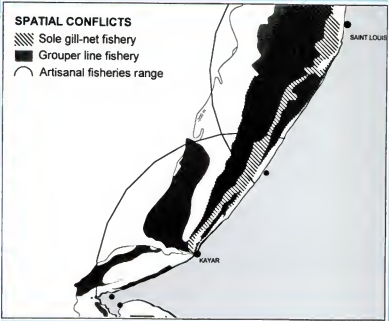
Geographical information systems

Applications to marine fisheries



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Food and Agriculture Organization of the United Nations

Geographical information systems

Applications to marine fisheries

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Sustainability of marine fisheries sectors has yet to be achieved and improved planning, taking into account conflicting marine uses and scarce resources, is therefore required. Consideration here is given to the use of management approaches which take a spatial viewpoint on differentiation in access to resources, of their rate of exploitation and of bioeconomic interactions within the sector and between fisheries and other sectors.

In order to understand and plan for increasing rates of changes of ocean use, infrastructure and socio-economic spatial patterns, the FAO Marine Resources Service is promoting the use of Geographical Information Systems (GIS) to access and use the range of relevant information available, through a number of workshops and training courses.

The present report is aiming at disseminating technical material to a larger audience: marine fisheries services of those governments concerned with fisheries research and management/development planning, plus workers in environmental fields, remote sensing, universities, etc.

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ABSTRACT

The late 20th century has witnessed increasing crises in the world's marine fisheries. A causal analysis of these reveals that a common element are various manifestations of spatial inequity. This most frequently includes the inequity of access rights to the resource, but factors such as variations in resource depletion, spatio-temporal variations in stock recruitment, the imposition of regulatory zoning, destruction of marine ecosystems and the siting of mariculture facilities are other examples. To resolve some of these problems, management practices must be improved. As has been shown in other fields where spatially related problems occur, there is now a promising tool, Geographical Information Systems (GIS), which, combined with other analytical tools and models, could allow for improved spatial management. GIS are basically integrated computer based systems which allow for the input of digital geo-referenced data to produce maps plus other textual, graphical and tabular output. The essential usefulness of GIS however, lies in its ability to manipulate data in a large number of ways and to perform various analytical functions so as to produce output which makes for more efficient decision making.

As with many computer based systems, the key to GIS success lies in the acquisition of suitable data. The various means by which both primary and secondary data can be located, gathered, accessed and stored are described. Data acquisition methods vary from simple surveys, questionnaires and counts through to the access of secondary digital databases via on-line networking capabilities. Once data has been acquired it is only useful to a GIS when it has been formatted, processed or structured in a way which the system will understand. The various ways of doing this are introduced. GIS's can function in an almost limitless variety of configurations of hard and software. The basic elements of these are described, as are examples of some of the software packages. Before a GIS is implemented into a fisheries management programme, then there are two major areas of consideration. The first of these concerns the potential that GIS might have as a management aid. Seven potential database areas for management are described in some detail. The second area considered is that of how best to implement a marine fisheries resource GIS, along with how to ensure that sufficient guidance and support can be obtained to assure its continued success. The paper concludes with an examination of some case studies covering a range of marine fisheries related topics.

PREFACE

This Technical Paper materializes, as probably other Papers do, from the topicality of several convergent processes and needs. Thus, the authors recognise that a series of strands of human progressive processes have reached a current developmental point such that they can now be unified, with the purpose of bringing about positive gains in the field of fisheries management. We can briefly allude to these processes and needs.

(a) The world extraction of fish and other biota from marine sources now appears to have reached a plateau, with FAO data showing that marine fisheries catches have not risen over the past five years. With fishing effort increasing, including technological improvements and applications, then there must be some doubt as to whether present catch rates can be maintained.

(b) Following enhanced perceptions of a deterioration in the world's natural biodiversity, which has been particularly recognised over the past 25 years, a strong conservation ethos has become apparent at many societal levels. This has been particularly noticed since the Rio de Janeiro Summit of 1992, and with the subsequent promotion of its Agenda 21, which aims to promote environmental consciousness upwards from a local level.

(c) Arising from both (a) and (b) above, and from the fact that resource exploitation in all spheres is occurring at an accelerating rate, there has been an increasing recognition of the need for the management of natural (or "wild") resources. This is to be seen in the setting up of a range of authorities, pressure groups and government organisations at all levels, which are directed towards the environment, conservation, enhancement and protection.

(d) The information technology era has spawned an explosion of computing functionality. One manifestation of this has been in the emergence of Geographical Information Systems (GIS), with their capability of offering a tool for the varied management of all problems having a spatial connotation. Their worth is now being amply demonstrated in a wide variety of fields. One of their main strengths lies in the recognition that spatial visualization is of major importance in the armoury of ways in which humans can best acquire information.

(e) The need for information as a means of expediting management has grown almost exponentially over the last few decades. This has resulted in the so-called "data explosion", with its needs to invest in methods of collection, storing, processing and outputting of data and information. Digital technology has developed, and the world is accumulating, by various means, vast databases of potentially useful data. With this explosion has come dramatic data price reductions and processing efficiencies.

So we would argue that the substance of what is presented in this Paper is the result of the merging of these five strands of human progression. Since each of these strands is so broad, then potentially the Paper might have a very wide audience among conservationists, ecologists, managers, geographers, etc, and we would hope that this should be the case. Realistically however, the Paper is most likely to be of interest to a more specific audience. Now that GIS

has been shown to be a success in a variety of fields, then there must be a range of personnel who work in various fisheries fields who might wish to find out about its functionality. They might be working in fisheries research, fisheries management or in fisheries education, and this Technical Paper is aimed mainly at this audience. We believe that the content should be understood by readers at a variety of educational levels, though generally it is pitched at undergraduate level.

We have been extremely conscious when assembling the contents, that the fields of both marine fisheries and GIS are varied and to an extent complex. This being the case, it would be impossible to put together in one volume a complete "Do-it-yourself Fisheries Management GIS". What this volume does therefore is to set out, in as straight-forward a way as possible, all the fundamentals and the potential that GIS has to offer in the marine fisheries field, i.e. to point the prospective GIS user in the right direction. There are certain more peripheral areas of GIS which we have deliberately not pursued in detail, either because they are exceptionally complex or because they are areas which might apply to computing in a more general sense. Examples of these would include error propagation, national transfer formats, data standards, copyright law, data modelling and statistical analyses. We have usually indicated where information on these can be obtained. It is also worth pointing out that nearly everything discussed in this Paper could apply to fisheries management which might be necessary on larger inland lakes.

As a means of providing a complete overview of this Technical Paper, Figure 1.3 illustrates its progression using a systems approach. The Paper itself commences with a detailed examination of why the management of fisheries could best be looked at as a spatial problem. Basically this means that many of the problems which the industry faces are a result of some manifestation of spatial inequity, i.e. unequal access rights to the resource, variable resource distributions, management practices which vary spatially, unequal spatial fisheries efforts, etc. We then briefly discuss the emergence of GIS in terms of what it is, how it developed and how it could be useful. Chapter 2 is devoted completely to the fundamentally important task of primary data gathering. Without large quantities of accurate data the system simply cannot function. Since the range of data collecting methods is so vast, we can only describe a few of them briefly. The description covers a hierarchy of methods, starting from several manual methods which use no equipment and proceeding right through to complex methods using advanced electronic equipment. Our next chapter (No.3) sets out the variety of ways which avoid primary data collection, i.e. through the acquisition of secondary data. This data is held mostly in the form of printed maps, tabular data sets and various digital data sets or databases such as remotely sensed imagery. We also explore some of the concepts comcerned with computer networking as a data source. Before any of the collected data can be of any use in a GIS, it has to undergo various forms of preparation. The various methods are described in Chapter 4. This is the first chapter which may introduce many entirely new concepts to a fisheries audience, and consequently there are many areas from this point on where the reader may wish to pursue ideas and themes in more detail elsewhere. Since this is the case, suggested sources for further information are provided in the text.

A GIS is fundamentally made up of hardware, software, data and operative personnel. Chapter 5 describes the range of hardware and hardware configurations which could be used, and it gives a necessarilly brief coverage of some of the software which is available. We have tried to restrict our discussion here to only those items which are directly related to GIS. This applies especially to the software since it is possible to link all kinds of packages to a general GIS in order to gain added functionality. Having arrived at an assembled array of data, hardware and software, the GIS can be made operative. Chapter 6 is devoted to outlining in broad terms what the functions of GIS are. We describe the main pre-processing functions which are designed to change the data into some useful form, the manipulative and analytical functions which allow for a wide range of operations, processing and analyses to be performed, and finally the ways of displaying and outputting the information. It is also necessary to explore briefly the fundamental area of database management. Having seen what GIS's are capable of doing, in Chapter 7 we look at their potential uses in the field of fisheries resource management. We begin this chapter by outlining, in a cautionary way, some of the main problems to be overcome (or coped with) in the use of GIS in this management area. Bearing these limitations in mind, it is feasible to direct a fisheries GIS in a number of directions, or towards the solution of problems in a range of fisheries associated fields. Seven major database areas are defined and discussed, although of course it would soon be obvious that these main areas could be sub-divided or integrated in a limitless number of ways.

If the potential GIS user has decided to adopt the technology then this is certainly no straight-forward matter. In Chapter 8 we consider all the necessary stages which must be gone through if the adoption is to prove successful. These all form part of the implementation procedures. Advice is also given on how guidance and support can best be obtained in order that the GIS can continue to operate in a satisfactory way. The Technical Paper would not be complete without giving some ideas on how a variety of marine GIS's have been successfully adopted throughout the world. We have therefore selected and detailed, in Chapter 9, a range of case studies which should give a thorough overview of the potential which GIS has to offer at this early stage in its adoptive life. The Paper concludes with a look at the current direction in which the main trends in GIS are moving, and it offers a view of the place of GIS in future fisheries management.

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CHAPTER 1 - INTRODUCTION

1.1 The Spatial Management Needs for Marine Fishery Resources

Marine fisheries are the world's most spatially extensive economic activity. They are carried out in a fairly intensive way over approximately 15% of the Earth's surface and extensively over a significant proportion of the remaining maritime areas. For as long as any reader can recall the marine fishery industry has been in crisis. From soon after the initial exploitation of marine resources there has probably always been a degree of crisis but, whereas originally crises were dominantly of a local nature, they have increasingly become manifest on the international stage. It could be argued that media projections have simply publicised these crises but this does not appear to be the case since any well researched study of developments in the fishery industry reveal that both the number and range of problems are increasing in an apparent exponential way (McGoodwin, 1990: Hinds, 1992; FAO, 1993; Brown, 1994). A timely account of the overall fisheries crisis has recently taken up a complete special edition of "The Ecologist" (Vol.25, No.2/3, March-June, 1995).

As well as being aware of these crises, most readers will be fairly familiar with the range of such problems. Thus, in general terms, they are connected with matters such as pollution, coastal zone degradation, over exploitation of resources, resource allocation disagreements and conflicts, habitat destruction, etc. It will also be apparent that each of these problems can vary enormously in their scale, and that in different marine resource areas, one or other of the problems may take precedence over the others. Indeed, in some geographic areas, the degree of crisis may still be relatively innocuous or almost non-existent.

What may not be quite so obvious to the reader is that virtually all the problems (or individual crises) have a spatial dimension. To elaborate on this, it can be imagined that the root of the problem lies in the fact that there exists either a fundamental spatial inequity, or spatial uncertainty or spatial differentiation. To take a simple example. If a build up of a potentially harmful substance occurs in an area then this may be referred to as pollution. The substance may in fact occur in minute quantities over a wide spatial area, but it is only generally recognised as pollution per se when the concentration reaches a level which is regarded as harmful. This harmful level of concentration may only be measured as occurring in a given, calculable area. So there exists spatial differentiation in the occurrence of the substance. Similarly, it can be easily envisaged how over-fishing may be a result of spatial uncertainty or that the need for resource allocation arises from both the existence of spatial differentiation of a particular stock and perhaps the spatial inequity of access to that stock. Table 1.1 gives a selection of recently published examples of spatially related fisheries problems.

Table 1.1 Selected Published Examples Illustrating Spatially Related Fisheries Management Problems

"Mapping the fishery and the resource should be among the priority tasks when planning for fisheries management..." (Caddy and Garcia, 1986).

"Two weeks earlier the Canadian minister of fisheries had imposed a two-year moratorium on fishing for northern cod off Newfoundland's coast." (McClellan, 1993).

"....the long term outlook for the (Japanese) distant - water tuna fishing industry in its current form is bleak." (Bergin and Howard, 1992).

"In recent years the rich marine environment along the coast of Norway has been repeatedly threatened by unpredicted toxic algae blooms and uncontrolled oil spills." (Johannessen et al, 1993).

"Heavy fishing in Russia's Sea of Okhotsk threatens to wipe out stocks of pollack, the most important commercial fish in the region." (IFM, 1994).

"Geographically, threats (from sea level rise) to finfish and shellfish could be highest along the low-lying, unconsolidated shores of the Gulf of Mexico, southeastern states, and much of the north Atlantic shore south of Cape Cod." (Bigford, 1991).

"Controversy flares over stocks shared by two or more states, as in the Northeast Atlantic, as well as stocks that straddle exclusive economic zones and the high seas." (Christy, 1993).

"Ask anyone about the North Sea's problems and they will most likely talk about pollution, algal blooms, sewage dumping and dying seals. But, according to many scientists, the greatest threat to marine life...is commercial fishing." (Gwyer, 1991).

"The devastating effect of the 1982/83 El Nino phenomenon, which increased the awareness of the role of the occans on global climate variability and the environment." (Loayza and Sprague, 1992).

"...and important habitats are being destroyed through the use of heavy equipment, such as demersal trawls, which trawl the sea-bed." (O'Riordan, 1992).

"All across what Jacques Cousteau has called 'our watery planet' the oceans' resources are gravely threatened." (Comte, 1993)

As a further way of illustrating the importance of spatial considerations in the management of marine fishery resources, Table 1.2 presents a random sample of the subject matter of papers presented at a recent Statutory Meeting of the International Council for the Exploration of the Seas (ICES). This is one of the major organisations who are encouraging and promoting an extremely wide range of fisheries research . At its Statutory Meeting, in Dublin, Ireland in

1993, there were 292 scientific papers presented, under a number of separate themes (ICES, 1993). Of these papers, 76% had themes in which it could said that spatial differentiation, disparities, etc., either formed the direct subject of investigation or they were implicated in the research findings as being of major importance. In other words, all of these 222 papers had themes whose subject matter lent itself to mapping.

Table 1.2 Selection of the Subject Matter of Some Papers Presented at the 1993 ICES Statutory Meeting Showing the Spatially Related Nature of the Themes

SUBJECT MATTER	SPATIAL CONCERN
Perspectives in coastal marine environment management due to new instrument developments.	To show how a new probe has been developed which calculates particle or phytoplankton distributions.
Environmental sensitivity mapping of the western Black Sea.	Mapping of degradation of the western Black sea as caused by pollution.
A software package for the assessment of the abundance and distribution of demersal fish.	Distribution of fish as recorded by various survey techniques.
Migration of Greenland halibut in the northwest Atlantic from tagging experiments.	Migration routes taken by fish from western Greenland.
Distribution of anchovy eggs and larvae in the Black sea.	To show long term changes in the spatial distribution of eggs and larvae from the north to the south of the Black Sea.
Features of the Baltic herring's spawning ground in the eastern Baltic.	To show the unique ecological and geomorphological features of the eastern Baltic.
Causes and management implications of recent changes in the growth rate of the South African spiny lobster.	Possible environmental causes in the growth rate reduction of this species.
The temporal and spatial structure of crustacean populations off some Spanish coasts.	Whether selected species of certain crustaceans aggregate in individual patches.
Dynamics of toxic dinoflagellates during an upwelling event off northwest Portugal.	To plot and measure dispersal of the species and to correlate this with wind variations.

Quite clearly, in an overall context, the present systems of fisheries management are not performing successfully. They have largely failed because the current level of fishing effort is too high and therefore the pressures on resources are too great -certainly in terms of the balance between resource extraction gains (outputs) and resource controls (or inputs) to the marine systems. And these are pressures which are constantly exacerbated by the continuance of rapidly growing human populations who utilize resources on a more or less open access ("free for all" hunting) basis. Thus, although the imposition of Economic Zoning (EEZ's) has been in force since 1982, this has done little to actually manage the resources in the sense of the careful monitoring and regulation of their levels of sustainability. And, as has been made clear in both Tables 1.1 and 1.2, it is not only resource utilization that is in dire need of spatial management. It is also the sustenance of coastal and aquatic ecosystems, the preservation and continuity of fishing dependent communities existing within bio-economic space, the location of enhanced resource production facilities (mariculture), the management of regulation itself, etc., etc.

Given that so many of the problems associated with marine fisheries and resource extraction can be shown to have their roots in spatial differentiation of one kind or another, then it is sensible to assume that the better management of space could well be a vital key to at least alleviating some of the present crises.

> "Mapping the fishery and the resources should be among the priority tasks when planning for fisheries management and should not be postponed until "complete" information is available, since redundancies or blanks in the information base will more readily appear in the process of elaboration." (Caddy and Garcia, 1986. p.32)

The theme of better spatial management of fisheries has been alluded to in several recent works, e.g. Ricketts (1986), Symes (1991), Charles (1992), Hinds (1992), Loayza and Sprague (1992), World Bank (1992) and Garcia (1993), so further details concerning most of the recommended management objectives will not be given here. Some matters concerning the optimum organisation of management, the spatial scale of management units, the integration of fisheries management with other interested sectors and the priorities for spatial management will be dealt with in Chapter 7.

1.2 The Growth and Need for Geographical Information Systems (GIS)

Any spatial management system needs data. Within certain limitations the maxim would apply that the more data the better. Certainly any management system falling under the overall heading of "Fisheries" or "Marine Resources" could not possibly function without having access to, not only large amounts of data, but also to data from a wide variety of sources in a potentially huge array of formats. Given these growing data requirements, then spatial management operations can really only function with the aid of Information Technology (IT) systems. There are now a wide variety of relevant computer based IT systems, some of which are general in their use, e.g. database management systems, spreadsheets, graphics packages, and some which have been developed specifically for fisheries (and related) purposes. These latter will be discussed in more detail in later chapters.

Spatial management, and associated activities such as location analysis and spatial modelling, is most successful when there is the potential for the whole operation, or a particular problem being tackled, to be visualised in a realistic or pseudo-realistic format. Visualisation is based on the fact that half of the human brain is intended to interpret visual images, and in working this way it can cope with considerable amounts of information. Visualisation in the spatial domain is conventionally carried out via mapping or graphical means, with a map usually being described as a 2-D simplified representation of spatial reality. Spatial analysis has always been most successfully performed via a whole range of mapping techniques. Even for the non specialist there is an old adage which says - "A map is worth a thousand words". Amongst those working in fisheries sciences, there has in the past been little recognition of the advantages to be gained for fisheries management from visually based mapping techniques - with a notable exception being the work of Caddy and Garcia (1986).

Over the past three decades there has gradually evolved a branch of IT which is specifically dedicated to mapping and spatial analysis. This emerging technology is usually referred to as "Geographical Information Systems" (GIS), though it has also been called "geo-data systems", "spatial information systems", "digital mapping systems" and "land information systems". Recently a new term has emerged - "desk-top mapping". This latter term is clearly a response to the fact that many GIS software houses are looking to promote GIS as part of an essential suite of tools which will collectively make management decisions easier. The term itself has undoubtedly arisen from the concept of "desk-top publishing". Also the term "geomatics" may be encountered, i.e. as encompassing the complete geographical information technologies. Exact definitions of GIS are made difficult since there are a wide variety of systems, each of which has evolved as a response to different software packages which are offering different functionality in order to capture various niches in the market. Any true definition however, must contain the idea that a GIS comprises of a collection of integrated computer hardware and software which together is used for inputting, storing, manipulating, analysing and presenting a variety of geographical data. Some authors contend that it is also useful to include the requisite geographical databases and skilled GIS personnel into the GIS definition. A GIS can then represent a set of working practices, management structures and data organised so as to utilise the spatial data handling functions of a software/hardware package.

Although there has long been GIS's which might have satisfied a non-IT definition of an information system, e.g. the 11th century British Domesday Book or a series of Irish Railway maps published in 1838 (Bernhardsen, 1992), the first digital mapping programmes were developed in Canada as the Canadian Geographic Information System in 1962. Since then developments have been rapid. It will not be important here to chronicle the evolution and growth of digital GIS, but useful sources for obtaining this information include Burrough (1986), Dept. of Environment (1987), Goodchild (1988), Tomlinson (1989), Star and Estes (1990), Faust et al (1991), Maguire et al (1991). What might be more relevant is to briefly see what those factors are which have led to the recent surge in digital GIS. The main developments can be listed as:

a) The proliferation of data. Over the last two decades there has been a surge in the developments of data gathering methodologies. The technology behind some of these will be

briefly examined in Chapters 2 and 3. This surge has resulted from the genuine need to see better management strategies implemented and from technology led applications, such as the growth in remote sensing, with its associated digital data output. Data is also much more widely available as specialist data gathering agencies emerge, plus the increasing ability to electronically transfer data.

b) The reduction in computing costs. According to Rhind (1990) "...the cost of computing power has decreased by an order of magnitude every six years over the last 30 (years); thus what cost £1 to compute with 'state of the art' equipment now would have cost about £10 000 (in 1968)." In other words today's US$1 000 personal computer (PC) can do roughly the same as a US$1 000 000 mainframe computer could do 20 years ago. This trend is certainly continuing and thus the balance between costs and benefits have shifted significantly in favour of increased markets and opportunities for GIS.

c) The integration of parallel developments. For the most part, GIS has been technologically driven. The applications stage of most IT systems lies at the core of a vast array of associated technology. This technology can usually be linked in an almost infinite number of ways so as to achieve any desired output. Not only have there been rapid developments in the requisite hard and software fields, but also in associated IT fields. For GIS these include computer aided design (CAD), remote sensing (RS), spatial and image analysis, digital cartography, surveying and geodesy, computer graphics, photogrammetry, etc. Figure 1.1 gives an indication of the progressive developments which have led to GIS availability on desk top PC's.

d) Increasing demand for GIS output. There are several perspectives on demand, all of which are exhibiting extraordinary growth rates. To give some examples:

i) GIS is being integrated into the management of a widening range of both public and private companies. GIS is also driven by popular demand for simple spatial map packages to identify markets, for real estates sales, etc., e.g. Atlas/GIS.

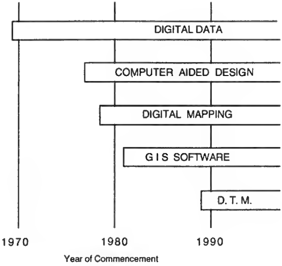
ii) Quoted growth rates for GIS installations vary from about 14% per annum (Payne, 1993) to 35% per annum (Frank et al, 1991). This would obviously be a function of systems types, the number of systems already installed, individual countries, etc., plus what costs might be included in the installation.

iii) The numbers of organisations, conferences and professional publications dedicated to GIS themes.

iv) An increase in the number and variety of GIS related courses both at University level and as offered by the major software houses.

v) The growth of national research centres for GIS in many developed countries, and increasingly in developing countries, plus the move towards international standards in GIS.

So it can be seen that the current rapid emergence of GIS is part of a complex amalgam of processes which are acting in unison to the extent that a cycle of GIS progress has been achieved - "Success breeds success". It is difficult to obtain precise figures on the global market for GIS, e.g. the CCTA (1993) quotes estimates that the 1992 revenue for GIS hardware, software and services was US$2.33 billion, having risen from US$1.98 billion only one year previously, whereas Frost & Sullivan (1994) reports that global GIS revenues were US$1.24 billion in 1993,



D. T. M. = Desk Top Mapping

Figure 1.1 The Inception Periods for the Major Developments in Desk Top GIS

having risen from US$657 in 1989. The Frost & Sullivan figures probably exclude all hardware. At the present time the U.S.A. and Europe completely dominate the GIS market, but the fastest growth rates are forecast for the Pacific rim area (Frost & Sullivan, 1994). By the end of the century the annual sales of software and services will be about US$4 billion. Rhind (1993) has shown the following recent growth of the GIS market in Europe by various sectors of the economy (Figure 1.2).

During the three decades of GIS development it is most significant that there has been a fundamental shift in the main factors controlling this development. In the early period, the late 1960's and the 1970's, considerations of computer technology lay at the heart of GIS functionality. During the 1980's the accent gradually swung from hardware technology to software functioning. Now that the range of GIS functions that can be performed is vast, the accent for the 1990's has shifted towards database management. The ability and need to cope with vast amounts of data is growing exponentially. Data must be captured, stored, transferred, shared, maintained and generally managed. The characteristics of the database, the ease with

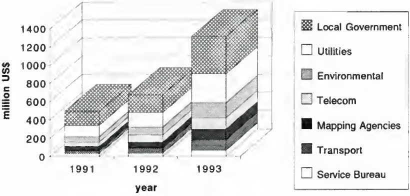


Figure 1.2 Recent Sectoral Growth in the European GIS Market

which the GIS can interact with it, and the care taken in designing a structure for the data to be stored all now have the major influence on GIS effectiveness.

In looking at this brief synopsis of the development of GIS, it seems pertinent to pose the question as to whether GIS has now become a new discipline, or whether it must be regarded as a sub-section of some existing discipline, e.g. perhaps "geography", or "cartography" or "computing". According to Obermeyer (1994), it would appear that GIS does not have the necessary credentials to stand alone as a discipline, but it certainly possesses the characteristics of a profession, i.e. a discipline in which there is a body of knowledge, expertise, and a professional culture. There have also emerged (in some countries) GIS organisations, a code of ethics and there is now emerging a body of standards which are presently being formulated at national levels, but which should in the future be universal. It would certainly be false to categorise GIS as being a sub-section of any one discipline, although in reality it is true that most workers in GIS have their origins in the field of "geography".

At this early stage in the Technical Paper it might be useful to illustrate the types of tasks for which GIS are suited. Table 1.3 (from Rhind, 1990) gives a simple introduction to the types of practical questions which a GIS can answer.

Table 1.3 Practical Questions Which GIS May Answer

QUESTION	TASK TYPE
1. What is at....?	Inventory/Monitoring
2. How big/long is....?	Quantification
3. How do I get from/to....?	Inventory/Monitoring
4. Where is....?	Inventory/Monitoring
5. What has changed since....?	Inventory/Monitoring
6. What spatial patterns exist...?	Spatial analysis
7. What if....?	Modelling

The first question simply seeks to find what exists at a particular location, e.g. a landing site, a port, a processing plant, etc. The second requires the GIS to calculate areas or perimeters, e.g. "How big is this lagoon and how long is its shoreline?" Question 3 is a route finding task, e.g. route finding GIS are now being installed in motor vehicles and they allow for the optimising of any specified route. The fourth question requires the GIS to search through geographic space in order to find the location where certain specified conditions can be met, e.g. "In which ICES fishing area was most Norwegian herring caught last April?" The fifth question allows for the spatial differences to be shown and calculated between any given time periods. Question 6 allows for more sophisticated geographic patterns to be displayed, e.g. "Show me the location of all areas of a continental shelf which are between 50 and 100 metres in depth and have a coral substrata." The final question allows for modelling, both of a theoretical or practical kind, e.g. "If I create a 20km wide buffer zone through this water body in which fishing will be prohibited, about what quantity of stock might I protect?"

Given this wide degree of functionality, GIS's have now been successfully adopted in a wide range of fields. Typical of these are forestry, where improved management is now possible with regard to such functions as species and wildlife mapping, timber yield calculations, the 3-D visualisation effects of proposed logging programmes, the impact of various public access or conservation measures, etc. Other fields in which GIS have had a major impact include local authorities (for highway planning, route scheduling, park management, etc), the utilities (for pipe management, emergency repairs, stock location inventories, etc), in the emergency services and in a wide variety of private companies (frequently for the optimising of business locations). Applications of GIS to marine fishery resources, or indeed to any marine applications, have presently been very limited, being mostly confined to peripheral areas such as coastal zone management, pollution modelling and controls, mariculture and shoreline mapping. The case studies in Chapter 9 will provide more details. Table 1.4 provides some reasons why marine applications of GIS have been slow to materialise. There is now, however, a growing literature from authors and research workers who can see the potential for marine applications, e.g. Caddy and Garcia (1986), Humphreys (1989), Jeffries-Harris (1992), Simpson (1992), Green and Stockdale (1993), Ibrekk et al (1993) and Caddy et al (1995). The potential and possibilities for these and other marine GIS applications will be studied in Chapter 7.

Table 1.4 Reasons Why Marine Applications of GIS Have Been Slow to Materialise

* The difficulties in mapping many marine species distributions, especially in a 3-D environment.
* The fact that the marine environment is constantly changing, i.e. it exhibits a high time/space variability.
* The high costs of obtaining marine related data.
* The large spatial units which need to be covered.
* The lack of recognition of the spatial aspects of fisheries management.
* The cooperation problems which need to be overcome in data collection.
* The difficulty of defining boundaries around "fuzzy" marine resource distributions.
* The problems of storing the huge amounts of data which are necessary for a reliable marine GIS.
* The lack of suitable databases in many areas of fishery resources.
* The lack of integration and/or the fragmentation of decision making amongst those responsible for fisheries management.

We should not conclude this introductory section by leaving the reader with the impression that GIS's will be an immediate answer to all fisheries management spatial problems. This is far from being the case. GIS's are immensely complex in that they make penetrating demands in terms of all aspects of their implementation. We are thinking here of factors such as data needs, expertise and training, equipment and sophisticated software plus the necessary agreements on data exchange, structures, and formats between the interested parties. Legal aspects with regard to copyright law and data ownership can also be immensely problematic. On top of these functional matters, GIS may be required to operate in an organisational or institutional milieu which is simply not prepared or ready for such an advanced technology. Given that these constraints are indeed a reality, then GIS adoption by fisheries managers will at best be a progressive process. But, given the nature and urgency of the fisheries management crisis which now pervades, then GIS is undoubtedly likely to prove the most efficient of all the available information technology tools.

1.3 The Plan of this Technical Paper

Publications of this sort are inevitably fairly complex. What is being attempted in one fairly short volume is to synthesize subject matter from the two extremely diverse fields of fisheries management and geographical information systems, in order that it is succinct, readable and informative. This is a process which can guarantee a degree of failure in so far as generalisations and omissions are certain to occur. Because we recognise this, then where possible suggestions for additional reading have been made and in many cases the reader would be strongly advised to follow these up, i.e. certainly in cases where sufficient clarity has not been given or where the reader has a particular interest.

An attempt has obviously been made to put the material in a logical sequence. Figure 1.3 is a schematic or systems diagram which hopes to portray this logic. Apart from the Introduction and Conclusion, the other nine chapters are shown as occupying a progressive sequence having five hierarchical levels. Chapters 5 and 6 make up the core of a GIS in terms of a functioning whole. Chapters 2, 3 and 4 are essentially a progression towards assembling the inputs to the GIS, whilst Chapters 7, 8 and 9 are essentially concerned with deriving outputs from a GIS. We have, in a simplistic way, tried to indicate flows through this total GIS. It would clearly have been possible to construct an alternative "web through the maze" as indeed many other authors in the GIS field have done.

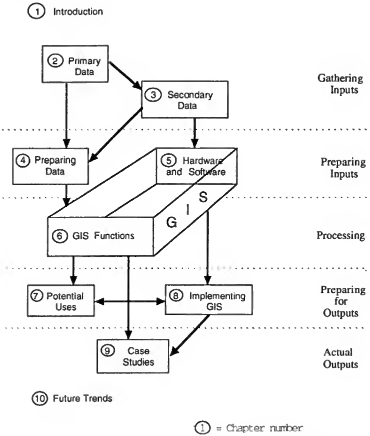


Figure 1.3 A Schematic Diagram to Show the Structure of this Technical Paper

CHAPTER 2 - THE ACQUISITION OF PRIMARY DATA FOR A MARINE FISHERIES RESOURCE GIS

2.1 The Importance of Data Collection

At the beginning of section 1.2 we highlighted the importance of data to the task of spatial management. It will be clear therefore that a GIS cannot function without data, and that generally the more data there is then the greater versatility that a GIS will have and the greater will be the potential functionality of any GIS. With regard to the implementation of GIS generally, the situation has now been arrived at whereby considerations of data are more important than issues concerning hard or software. This situation exists because, given the commercial advantages to be gained, a great deal of research effort and funding has been devoted to technological improvements in the performance of computer systems per se. For very little capital outlay processors can now perform countless functions at incredible speeds and software is cheaply available that will allow for the pursuance of an almost limitless number of requisite tasks. Conversely, given the infinite forms that data may take then it is clearly a far harder task to expedite its collection. So, whereas as recently as five years ago it was hardware and software considerations that formed the first point of interest in establishing a GIS system, it is now considerations of data acquisition that have come to the fore. Costs concerned with data acquisition are now considerably more than those for purchasing hard or software, e.g. Frank et al (1991) estimate that the ratio of the costs for hardware, software and data respectively, over the lifetime of a GIS, are 1:10:100.

At the outset it seems relevant to introduce a few cautionary words on data and its uses. Initially, in this study we define "data" as purposeful observations which have been recorded and stored; this is different from "information" which we would simply define as organised data. Data itself may usefully be classified as being "primary" or "secondary" data. The former represents more a process than a state in the sense that it is facts which are being gathered, usually in order to be converted into secondary data. Thus secondary data represents available data or information which may be refined and/or organised primary data, and which may be available in a range of formats. Table 2.1 gives a summary of ways in which both primary and secondary data collection processes can be categorised. This chapter and chapter 3 will be elaborating on much of this table, and many of these introductory remarks concern both types of data. Figure 2.1 gives an initial indication of the data "flow" both in its collection stages and as it proceeds through the GIS. Again, Chapter 6 will elaborate on the data processing functions which occur within the GIS box. There are some special problems related to the collection and handling of data that is related to marine environments and resources, and some of these are discussed in section 7.2.

Table 2.1 A Summary of Primary and Secondary Data Collection for a Marine Fisheries Resources GIS

	PRIMARY DATA	SECONDARY DATA
DATA FORMAT	Objects e.g. Fish Water Fishing vessels Ports Coast etc.	Tables Photographs Textual material Diskettes Maps & charts Books RS & Acoustic images Digital databases
DATA SOURCES	The Real World	Libraries Remote sensing centres Government offices Mapping agencies Hydrographic offices Research institutes Digitizing agencies
COLLECTION AND ACQUISITION METHODS	Counts Measuring Surveys Questionnaires Sketching Photography Remote sensing	Networking Digitising Scanning 'On-line'searching Microfiche Database entry
EQUIPMENT	Measuring Equipment Cameras Data loggers Sensors Acoustic equipment Positioning systems Trawl survey equipment Sampling gears	Scanner Digitiser Computers & peripherals Modems Image analysis equipment

Once the gathering of data has commenced, we would strongly advise that a meta database (or "informational database") is established at the earliest opportunity. This is catalogue or listing, held in digital form, which gives details on datasets found which may be potentially useful, i.e.

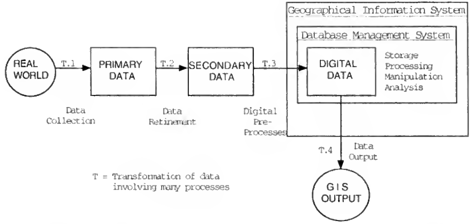


Figure 2.1 The Transformation of Data Via Various Stages of the Total GIS Operation

such information as spatio-temporal coverage, appropriateness, date of data collection, source of the data, format and the quality of the data should be recorded. This is described in more detail in section 4.4. Meta databases are important since the data holdings are soon likely to grow exponentially. We would also advise that every effort be made to ascertain the quality of any data which might be considered for use. Quality would include not only the level of accuracy but also its completeness, its detail (or resolution) and perhaps its level of aggregation. If mistakes are embedded then they will multiply once the GIS becomes operative. For most data relative to a marine resources GIS it will be important to understand the sampling techniques which have been used to compile the data. What are their tolerances, variances, etc. Efforts should be made to standardise the quality and methods of sampling to a unified high level. Copyright issues might need to be checked before any data is used.

2.2 The Data Needed for a Marine Fishery Resources GIS

Although in Chapter 7 we will be setting out some potential database areas, it will be impossible to decide exactly what data is needed for a marine fishery resources GIS until the potential user has established clear aims and objectives for the system. As Roberts and Ricketts (1990) have noted, with regard to a marine resources information system, "...problems concerning the anticipated use of the GIS and related databases can usefully be minimized with the development of a clear statement regarding its potential relevance and use in given instances....This clearly places the onus on project managers to objectively and unambiguously define the applications and objectives of the particular project and to determine the scope of the GIS applications." For

many reasons the aims and objectives themselves will vary between users or organisations, but once established it will be possible to work out which areas of data collection it is useful to concentrate upon. Since not all areas of a marine fisheries GIS can be instigated simultaneously, it is likely that certain areas will emerge as being important from an "emergency" or "urgency" viewpoint, whilst other areas will be preferential from a feasibility aspect, i.e. "we can get this going quite easily because we have the data."

Certain core fisheries management aims and objectives are likely to be almost universal. For instance, concerns such as the maintenance or improvement of the coastal zone will be one clear priority, i.e. since the well-being of estuaries, lagoons, mangroves or coastal shallows are vital to the life cycle of many marine resources. Another core aim or objective, though more difficult to achieve, might be the monitoring of fish yields by species for given marine unit areas. Whilst it is not our function to decide what any aims and objectives should be, we should point out that their establishment is crucial to the success of a GIS approach and that their achievement will inevitably involve discussions and decisions across a spectrum of involved parties.

Having established aims and objectives, such as those suggested, it may be a relatively simple task to list the main types of data required. Thus, in our coastal zone management example, the user would clearly require data (for any specified geographic area) on existing land use, any proposed land use changes, land ownership, transport routes, etc., and he may want additional data on factors such as height or gradient of the land, sea-bed types, existing natural vegetation, locations of jetties or harbours, local population densities, etc. Obviously, for the example of monitoring fish yields, then essential data might be that which is shown in Table 2.2. These brief examples simply illustrate the range of data which might initially be required; after a while the GIS user would be a position to add to these basic data requirement lists.

Table 2.2 Essential Data Required for a GIS Which is Being Used for Monitoring Fish Yields

* The boundaries of geographic unit areas or fishing zones.
* Catch by species or species group as determined by various catch data.
* The size ranges by species.
* The fishing effort by unit area.
* Catch rate data per species or species group.
* Bathymetric data for the appropriate area.
* Water quality data for the area.
* Fishing methods and gears used.
* Seasonal or other temporal information.
* Biological and ecological features.
* The state of exploitation of the stocks.

2.3 Collection Methods for Primary Data

In the collection of primary data we are essentially considering the collection of raw data in the field, or more frequently for marine resources, in the water! Some of the data which may be of value to a marine fisheries GIS could be collected in any one of several ways. The actual methods employed, the degree of detail collected and the volume of data collected could depend on a number of factors, e.g.:

a) The time available,
b) the capital outlay planned,
c) the skills and number of personnel involved,
d) the availability and usefulness of any existing data,
e) the size of the area being studied,
f) the equipment available,
g) and the purpose for which it is required.

Data acquired by primary collection techniques could be in many forms, e.g. photographic, numeric, digitally encoded, labelled pictorial, written descriptions, colour coded graphical, and it could be used in several ways. In this section we propose to describe some of the important data collection methods under separate sub-headings which progress from the simple to the sophisticated, and we will discuss both the data collection processes and any equipment involved. Space prohibits anything but a brief descriptive examination of each - those wishing to find further information should consult any of a number of more specialised texts. Within any of the methods described, it would be possible to acquire varying degrees of skills and there are often recognised rules or conventions in collection techniques which are devised so as to ensure degrees of detail, accuracy, consistency, etc. Most methods described require that preparatory work is undertaken so as to achieve the desired level of reliability. This may include being familiar with the use of statistical and sampling techniques i.e. since for many forms of data collection it will be impossible to obtain a complete data coverage.

2.3.1 Manual Methods of Data Collection Using No Equipment

a) Direct mapping or survey sketching. There will be many instances, especially when dealing with the mapping of very small areas, when it could be necessary to draw maps or plans by hand. For instance, if a new mariculture facility were being planned, perhaps on a coastal flood plain area, then it might be necessary to make the first draughts by hand. This is especially true in areas where no detailed or up to date maps exist. Sketches or maps lend themselves to annotation and other form of labelling. They are inexpensive to produce and they can easily be upgraded such that they could form the basis of later digitising.

b) Interviewing. Though at first sight this method might not appear to be useful in a spatial context, in practice it is often the only means of obtaining certain sorts of data. Fishermen in any country might need to be asked questions about catches, operating gear, costs, market outlets, etc. Figure 2.2 gives an indication of the types of information gained from interviewing

community leaders in coastal sites in Libya (from Meaden and Reynolds, 1994). Fishermen are often familiar with all aspects of their occupation and they may be able to provide insights into local fish habits, climatic factors, water quality, marketing, fishing strategies, etc. It can also be useful to interview people who are not directly involved in marine resources exploitation, e.g. marketing experts, financial or credit experts or various extension officers. There is plenty of information which might only be obtained by means of interviewing, e.g. data on what conditions were like at some time in the past, species habitat preferences, the prevalence of endemic diseases and local transport availability. The disadvantages of interviewing is that the data obtained could be very subjective and it could rarely be converted directly to a mappable or statistical form.

c) Questionnaires and counts. These are obviously the major way of ascertaining certain types of information. They have advantages over interviewing in that they can provide objective data, much of which could lend itself to mapping. Questionnaires are a very good method of finding out about personal preferences, e.g. types of fish, type of fishing method used, target species, etc. as well all sorts of demand or market preferences. Although they are comparatively cheap to administer, adaptable to sampling techniques and they can provide data which is easily graphed and which can form the basis of written analyses, questionnaires should always be rigorously structured and methodically administered in order to eliminate any forms of bias. Data collected is usually entered onto a previously established form, although increasingly simple electronic data loggers are being used (see section 2.3.3.3).

d) Form filling. It is standard practice, especially amongst government departments, research departments and larger organisations, to have a range of forms which are required to be completed in order to fulfil supposed data requirements, or to comply with some aspect of the law. Example forms are shown in Figure 2.3. Since a standard form, which is often obligatory, is usually sent out to a large number of respondents, then there is the potential for a large body of useful data to be acquired. Clearly, the potential range of information which could be received is almost limitless and, since the respondents are not usually paid for the information they provide, then this can be an inexpensive form of data gathering.

2.3.2 Methods of Data Collection Using Simple, Non-electronic Equipment

Since there would be an almost limitless list of both methods and equipment we shall only mention a few of the major ones which could prove directly useful to gathering data for a marine fisheries GIS. It should be mentioned that, with the introduction of digital functioning in most data gathering instruments, then non-electronic equipment is rapidly becoming obsolete.

a) Photography. Although aerial photography is the most useful form of photography for GIS purposes, we shall consider it later along with satellite remote sensing (RS) (see Section 2.2.4.2), i.e. since they are both related RS techniques. Photography is of little direct use to GIS, though it can be very useful as a means of recording information, e.g. recording pictures of fish species caught for later identification, and remotely controlled cameras may be used for various underwater or deepwater survey activities.

TRAWL SURVEY • Densities for major species of bottom fish at trawl station • Size distribution of major species • Vertical profiles (temperature, salinity and oxygen) at trawl stations • Trawlable grounds
ACOUSTIC • Pelagic fish densities each mile sailed • Surface temperature each mile • Bottom condition (can be extracted from further analysis of echograms)
FRAME SURVEY OF COASTAL FISHING SITES AND COMMUNITIES (November - December 1993) • Landing sites - location - site type - maximum boat size accomodated - berthing facilities - fisher accommodation - fisher nationality distribution and rank order of representation • Facilities and services - fisher associations - co-operatives - training facilities - repair and supplies facilities for engines and hulls - food and commodities supplies (electricity, water, ice) - fish handling and marketing and processing facilities - commercializing channels - traders' buyers details • Boats - number and type at site - main characteristics each craft. > service status > length > hull construction > seasons of activity > deck features > engine type and power > type of gear worked > owner/crew number and activity • Species (for major species groups) - catch period - gear used • Other foot or shore based fishing activity - estimation of number of foot fishers, type of gear and target species
FISH HANDLING AND PROCESSING FACILITIES • Fish handling areas (opened or sheltered) • Ice plants, capacity and utilization • Chill, freezing, and cold storage facilities, capacity and utilization • Fish canneries, processing lines, equipment, capacity and utilization
AQUACULTURE SITE SELECTION • potential site locations • geographical features (topography, soil, access) • water quality • proposed type of aquaculture development

Figure 2.2 Fishery Information Sought in a Frame Survey of Communities Along the Libyan Coastline (from Meaden and Reynolds, 1994)

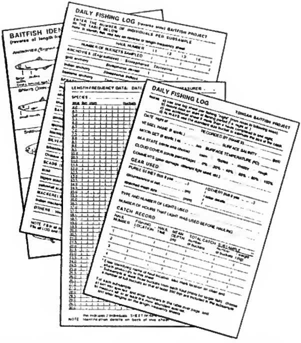


Figure 2.3 Examples of Standardised Data Collection Sheets Used on a Baitfish Project in Tonga (from King, 1995)

b) Site surveying or measurement. In the absence of data specific to small sites, which are perhaps being developed for mariculture or port activities, then surveying and measurement techniques will be necessary for planning purposes. There are an array of acknowledged measuring devices which can be used with little experience. For survey purposes, when levelling and accurate measurements are required, then there are a number of instruments such as clinometers, theodolites and abney levels which can be used, given sufficient knowledge.

c) Meteorological data gathering. It could well be important to a marine fisheries GIS to gather meteorological data, especially that pertaining to particular micro sites for which there is no other data, or perhaps to particular conditions at some time and place relating to a specific activity or event. Further details on the importance of meteorological data can be obtained from

Cushing (1982). There is a range of fairly simple measuring equipment available such as rain gauges, thermometers, barometers and anemometers. The use of these instruments is either self-explanatory or they can easily be referenced.

d) Trawl surveys. Most marine fisheries personnel will have some familiarity with the range of trawl survey methods which are used as a major source of information on species distributions and abundance. Since the processes involved in fishery resources surveys are extremely varied and sometimes quite complex, it is beyond the scope of this study to elaborate on these, i.e. more than to say that survey vessels will need to be equipped with an array of nets (usually purse seines and otter, beam or midwater trawls) and other items for the passive or active collection of samples. It is also essential that, in order to obtain valid data, the trawl survey itself is designed in a way which ensures the capture of statistically valid information. An example of the type of data gathered in a trawl survey is shown in Figure 2.4. Note that it has been prepared so that all the data received can be easily and accurately entered into the correct columns on a digital database. We recommend as further reading on various survey techniques Smith and Richardson (1977), Doubleday and Rivards (1981), Grosslein and Laurec (1982), Gulland (1983), Fogarty (1985), Hilborn and Walters (1992), Stromme (1992) and Gunderson (1993).

2.3.3 Methods of Data Collection Using Simple Electronic Equipment

In this section we will consider "simple electronic equipment" to be any item which can be used by one person working alone and which is reasonably portable, i.e. even though some of the equipment itself might be technologically fairly complex. Since one range of equipment, Global Positioning Systems (GPS), is quite new, and since it offers a huge potential for the gathering of marine data, we will look at this in more detail than the others.

As implied in Section 2.3.2 above, over the past decade there has been a considerable move towards the manufacture of data collection equipment which incorporates some elementary electronics. This has been of great benefit to the data collector for a number of reasons. Thus, items are invariably far lighter to transport, they can achieve greater degrees of accuracy, their prices are usually far lower than previous mechanical equipment, they are often easier to use and data collection can be greatly speeded up. Under this heading the equipment can be subdivided into two categories, i.e. (i) that which simply produces electronic read-outs and (ii) that which is able to store and download data for further use.

2.3.3.1 Electronic Read-Out Equipment

These devices can nearly all be classified as automatic measurement devices and electronic distance measuring instruments. They constitute a huge range of devices which are purposefully designed to give readings on any parameter for which they have been calibrated. A perusal through a science equipment catalogue reveals digital pH meters, digital thermometers, humidity/temperature meters, ultrasonic volumetric readers, digital light meters, water flow meters, electronic pressure gauges, various weighing devices, etc. Obviously the use of any such

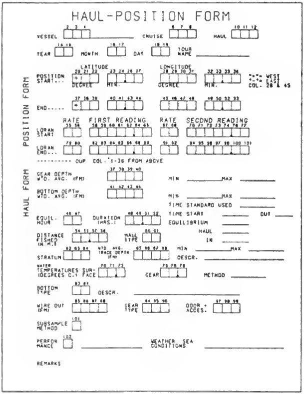


Figure 2.4 Example of a Data Collection Form Used for Trawl Surveys (from Gunderson, 1993)

device would assume that a systematic survey scheme had been planned and that at least some standard data recording form was available.

Since so many of the measurements which are made in collecting primary data will form the basis of further work, it has not taken equipment manufacturers long to realise the potential for making devices which can not only do the measurements but which can store them, either on floppy disks or via some fixed internal storage system, i.e. enabling the data to be captured in a digital format for export to another software package. Particular fisheries related examples include a "salinity, temperature, depth recorder" and a "marine temperature profiling system". In the latter a sophisticated temperature probe is lowered into any marine waters, and

temperature records are relayed back, at accuracies of 0.1 C, for disk storage and display. Temperature profiles can be built up, or the information can be used directly so as to concentrate fishing effort into areas where certain species are known to have temperature preferences.

2.3.3.2 Multi-Media Devices

A range of data input methodologies has recently emerged which may be generically referred to as "multimedia". Thus it is now possible to input to a GIS data from oblique aerial photographs, ordinary photographs, film or video images, graphics, animations, cartoons and even sound. Obviously, to be useful, these media must be converted to a digital format and, to be classed as a GIS, then some sort of geo-referencing is necessary. An example of a multiple media device would be the Still Video Camera. These small cameras offer full colour computer imaging by capturing the image on a small 2 inch re-useable floppy disk. Data can then be transferred to a host computer in a variety of formats for later use in perhaps a GIS or desk-top publishing programmes. Most multimedia devices are beyond the remit of this paper but the interested reader can obtain useful summaries from Parsons (1992) or Cassettari (1993).

2.3.3.3 Data Loggers

There are now a large number of specialist devices which are designed for use in the field and are therefore very portable. They may be semi-automatic, hand held, battery operated instruments which run simple software which has been specifically designed for a particular data recording task, e.g. a hand held survey laser which records azimuth range, heights, inclinations and co-ordinates for later input to other software. Alternatively, they may be automatic devices which are placed in some location where data needs to be constantly and regularly gathered, e.g. weather variables, air pollution monitoring or river water quantity or quality variables. Data entry into hand held devices may be via keyboard input or by pen plotting. Curtis and Bowler (1994) provide a basic description of how the UK Ordnance Survey are now starting to update most of their larger scale topographic mapping data via the use of pen plotters which are being used in the field on notepad computers (Figure 2.5). Intelligent data loggers are available which, for example, can switch between sampling strategies or which can do certain mathematical transformations, etc. The data obtained by loggers, which is typically numeric values or attribute information, is usually stored internally for later transference to another programme, though some systems may display readouts directly to the computer screen. There are now specialist software systems into which trawl survey data can be logged and stored for a range of analyses (Stromme, 1992). A summary of some digital data collection devices is given in Price (1992).

2.3.3.4 Global Positioning Systems

These are devices which allow the user to very accurately establish his location on the Earth's surface. Their ability to do this relies on 21 military (NAVSTAR) satellites which have been developed and launched by the U.S. Department of Defense, and which became fully operational in 1994. These satellites are in predictable orbits and they carry atomic clocks which allow them

Figure 2.5 Portable Pen Plotter for the Field Recording of Survey Data

to transmit highly accurate radio signals. As illustrated in Figure 2.6, the GPS user's position is determined by using a portable receiver which receives and compares the signals from at least three satellites. The receiver is able to perform elementary geometric calculations in order to establish the user's location (at the intersection of the three cones), which is usually given in latitude and longitude co-ordinates.

GPS can be used in two ways, i.e. autonomously or differentially. Autonomous GPS is where a single GPS receiver collects inputs from the satellites only. In this case accuracy may not be very great, i.e. typically from dozens to hundreds of metres. Inaccuracy is caused by atmospheric and ionospheric distortions, satellite clock or orbital errors and by intentional degradation imposed by the US Department of Defense (known as "Selective Availability") - imposed to ensure that 95% of GPS positions are only within 100 metres of their true position.

Differential GPS largely negates the effects of selective availability. It relies upon two GPS receivers (a base or reference station and a rover) that collect data simultaneously. The base receiver occupies a known co-ordinate and, for real time positioning, the rover GPS receiver can move anywhere within transmitting distance of the base receiver. The base receiver calculates correction values associated with the satellite measurements. These corrections can either be transmitted (for use in real time) or they can be downloaded and applied later. With "top of the range" GPS's, accuracies to within a few centimetres can be obtained using differential GPS, though typically it is 0.3 to 2.0 metres. Accuracy rates deteriorate with distance between the base station and the roving GPS at about 1 cm per kilometre. GPS requires a direct line of sight

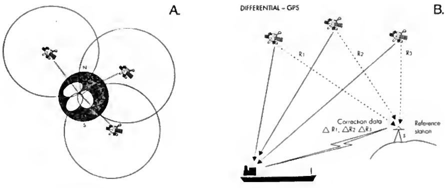


Figure 2.6 The Functioning of a Global Positioning System

between the receiver and each satellite accessed. At the present time differential GPS accuracy can only be obtained at sea in those areas where there are shore based differential stations, e.g. most of the north west European coastline (Figure 2.7), but with the launch of five Inmarsat-3 navigational satellites in 1996, sub-metre accuracy will then be possible worldwide (and the service will be free of charge).

Differential GPS is mostly being used for mapping and to accurately track moving vehicles or vessels. Recent advances in GPS technology means that it is now possible to utilize GPS to help map several thousand objects in a day. The potential that this has for a marine GIS is huge. The use of maps on land has always enabled positions to be quite accurately determined, but of course at sea there are few guides to exact location, especially when out of sight of land. Now it is possible for fishing or survey vessels to accurately determine where trawl hauls were made, where underwater obstacles occur, where water quality samples were taken, etc. Commercial marine equipment companies are already offering base receiver facilities for ships fishing in most of the north west European waters. Governments in many countries, including Japan, New Zealand, Australia, Chile, Canada, the USA and most EC countries, in order to monitor fishing activity, are either making it compulsory for vessels of certain types to carry satellite positioning equipment, or they are experimenting with the implementation of various GPS schemes.

The latest GPS equipment also includes software which can allow for the capture of any attribute or feature data, plus its GPS given position, so as to form a field mapping system. The data obtained can then be directly exported to most GIS packages. In marine use this would allow,

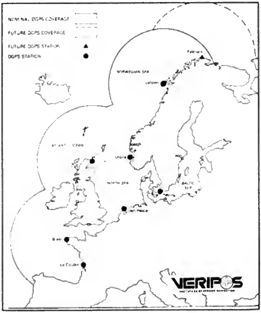


Figure 2.7 The Marine Areas of Northwest Europe Presently Covered by Differential GPS

for instance, for a survey vessel to continuously monitor water quality along any transect whilst recording the exact location at a rate of twice per second. The data could then be mapped in near real time. It is also possible to build a customised database complete with menus and data dictionaries, so that the GPS can function and record data in any required structure. Ridgeway (1994, personal communication) reports the development of an on-board "automatic position recorder" (APR) which has been specifically designed to both receive GPS information on a trawler's location (at 30 minute intervals) and to record the trawlers catch data, i.e. at the end of a fishing trip the vessel would have a complete record on disk of catch against location. The APR was seen as an alternative way of monitoring vessel location, i.e. from the use of a satellite communication link to a position transponder on-board the fishing vessel. The European Commission are undertaking trials of the two fisheries remote surveillance systems during 1995, with a view to introducing a surveillance system on all EC vessels from 1996. Further information on GPS can be obtained from Cross (1991), Leick (1990) and Gilbert (1994), and the Geodetical Info Magazine has a complete GPS special edition (Vol.7, No.3, November, 1993).

2.3.4 Methods of Data Collection Using Complex Electronic Equipment

In this section we shall limit our discussion to three major sources of data collection which would be of value to a marine resources GIS, i.e. (i) acoustic SONAR devices, (ii) satellite remote sensing and (iii) aerial photography. Although aerial photography does not necessarily use complex electronic equipment, we have included it here since there is now a rapid move towards the use of video air photography. We should also note that there are many sensors similar to those being carried in satellites, which can and are being used from aircraft platforms. The other two methods are complex in the sense that they require a good deal of expertise and are very expensive to install and/or to operate. The potential user should also be warned that the use of any of these more complex systems means that very large volumes of data will need to be handled and stored, and that advanced skills are required in processing the data acquired.

As an adjunct to the above, it is relevant to note that most of the larger fishing vessels in the developed world, and the majority of research vessels, now have the potential to be equipped with very advanced electronic instrumentation systems. The systems are primarily designed for navigation and for "fish-finding", and they might consist of a variety of components such as computer processing units, GPS, data loggers, navigational and plotting aids, digital charts, communication systems, and acoustic SONAR equipment. There is some indication that this degree of technological innovation is proving to be seen as extremely complex by those who are having to manage these systems. If as seems likely, GIS capability is added to these systems in the near future, then this can only make the situation even more complex. It now seems essential that moves are made towards systems integration, i.e. so that one "package" is capable of providing an intelligent on-board navigation and fish-finding capability. Failure to do this may soon make it very difficult for fishermen to provide management with requisite data and information.

It is likely that as the use of GIS for marine fishery resources analyses increases, then acoustic SONAR, RS and videography will become the major source of data. However, because these methods have been extensively discussed elsewhere, we shall only briefly describe each so that a recognition of their potential is fully appreciated. Since the acquisition of data using satellite RS techniques could not practically be made directly by those operating a marine fisheries GIS, in Chapter 3 we suggest actual sources for this data. We shall only be considering satellites as used for their data gathering capabilities and not in their communication or transmission capacity. For readers who are interested in obtaining further information on remote sensing, we recommend Curran (1985), Lo (1986), Butler et al (1988), Lantieri (1988), Drury (1990), Cracknell and Hayes (1991), Faust et al (1991), Foody and Curran (1994) and Petrie (1994), and for further information on various underwater acoustic systems we recommend Burczynski (1979), Johannesson and Mitson (1983), MacLennan and Simmonds (1992), Simmonds et al (1992), Foote and Stefansson (1993) and Gunderson (1993). For further information on aerial photography see Cassettari (1993) or Petrie (1994).

2.3.4.1 Acoustic SONAR Systems

The use of underwater acoustic or echo-sounding devices has two main purposes as far a marine fisheries GIS is concerned, i.e. to gather data for underwater mapping and to locate fish or other underwater objects. The location of fish is usually for commercial exploitation reasons but echo sounding is also used extensively in biomass survey work. In carrying out acoustic detection techniques certain pieces of equipment are essential:

(i) A Transducer - this instrument converts an electrical signal to mechanical vibrations (pulses or pressure waves) which physically move the adjacent water particles (Figure 2.8).

(ii) A platform - this carries the transducer and other equipment over the data collection area.

(iii) An echo sounder - this transmits and receives electronic signals to control the pulsing of the transducer and reception of the echoes.

(iv) A computer plus the relevant software systems to store transmitted data for later application to a GIS (or to other software analysis programmes).

(v) The necessary hardware to capture and view the transmitted echoes on, i.e. usually a Visual Display Unit (VDU).

Other equipment might be necessary such as fish netting gear to verify the species and the age or size distribution of observed fish.

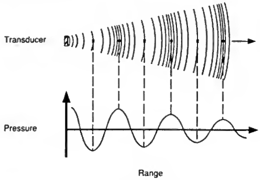


Figure 2.8 Propagation of an Acoustic Wave Produced by Vibration of the Transducer (after Gunderson, 1993)

In carrying out survey data collection, the transducer is generally carried or towed across the study area, i.e. suspended under the platform (Figure 2.9). This area will have been previously selected and a trawl or survey path will have been designed, usually in zig-zags or in parallel lines (see below). Obviously the extent of the survey will be dependent upon available time, finance, area of interest and whether or not anything has been located. Whilst the survey is in progress the transducer should be in continuous operation. The transducer pulsing occurs at intervals of typically one "ping" per second, though to avoid confusions with echoes being

returned from the sea bottom, pulse repetition rates in fact vary with water depth. It normally uses a frequency of 10-12 kHz with a beam width of 10-20 degrees and a bandwidth of 500Hz, though importantly all of these configuration values can be adjusted or optimised for specific data collection tasks, e.g. for the detection of bottom living species it would be important to have a narrow beam width and a short pulse length. When the sound pulse strikes an object it causes an echo which rebounds to the transducer. Given that the transducer's beam angle, ping rate, the speed at which the pulse travels and the speed of the towing vessel are known, then it is possible to detect where an object is relative to the transducer. Acoustic devices can operate to depths of 1200 metres and may either sweep continuously through 360 degrees or they may sweep at selectable speeds, resolutions and in selectable sectors. Figure 2.9 shows that there are variations in transducer configurations, i.e. ship mounted or net mounted, and Figure 2.10 illustrates how an acoustic scanner can vary the area being sensed, i.e. (1) a headrope mounted scanner can look up to 800 metres in front of the trawl; (2) in downlook scanning mode quantities of fish entering the net can be viewed and the trawl opening can be measured and; (3) in net profile mode the correct net opening geometry can be maintained.

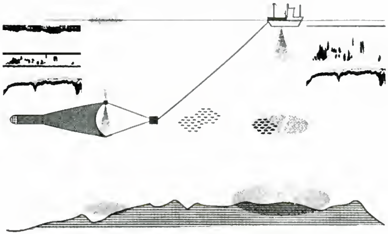


Figure 2.9 Basic Variations in Transducer Configurations

Echoes received are collected as marks, in black and white or in colour, along a strip of moving paper (or on a VDU screen or even speakers that convert the echo signal into audible sounds). The paper is calibrated so that the marks are drawn relative to the distance from the object - this produces an echogram, i.e. a visual image of what has been detected by the transducer. Clearly, this information can be collected and stored digitally for use in a computer. There are now a number of software packages which can convert the data into a variety of useful output forms (see Chapter 3).

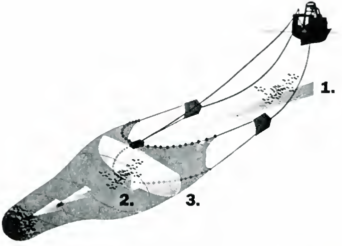


Figure 2.10 Different Acoustic Transducer Sensing Modes

Different characteristics of various aquatic species such as their size, shape, distribution, schooling habits, etc., means that the echogram will exhibit different marking patterns. An experienced user of the equipment may be able to interpret the markings so as to calculate fish densities (though not yet the species of an individual fish), and distribution patterns within the survey area. Often, for various reasons, this is impossible so target identification is then necessary using net trawls or purse seines, etc. The measurements obtained can be used as interpolation points which can form the basis of describing the total fish quantity and distribution over the entire survey area.

Whilst what we have described briefly here shows how fish numbers can be calculated, it should be noted that the compilation of bathymetric maps (Figure 2.11), or 3-D bathymetric images (Figure 2.12), using similar acoustic technology are equally feasible. Here, of course, the survey should only need to be carried out once, and there are no complications caused by the size of the object being detected or by its mobility. Additionally, what are called "ground discrimination units" are now available. These are echo sounders which are specifically designed to capture the data necessary to allow for differentiation between sea bottom types. Useful summaries on the application of acoustic methods to ocean mapping can be obtained from Talukdar and Tyce (1990), Miller (1991), Mills and Perry (1992) or Somers (1992).

As well as basic echo sounding devices to determine the presence of fish or the depth of the sea, new instruments are now being marketed which are described as "integrated information systems". This means that the one set of instrumentation can provide multi-window displays showing fish detection, catching operations, and water depth and they can function as a navigation aid. Other acoustic instruments have been developed solely for navigational use. It should also be mentioned that there a number of variations on the basic acoustic systems, e.g. there are multi-beam swath echo sounders, split beam transducers, sidescanning systems and combined sidescan/swath bathymetry systems (Figure 2.13). Potentials users should do some research before investing in any of this expensive technology.

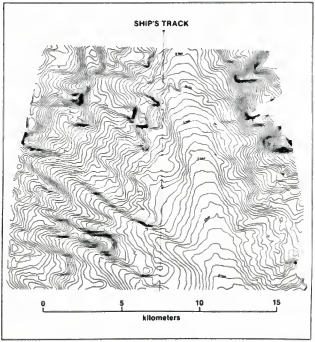


Figure 2.11 Typical Bathymetric Output Achieved from an Acoustic Bottom Survey

Having outlined the technological functioning of acoustic surveying, it is relevant to briefly mention some important considerations on survey design for estimating species numbers. Factors we consider here can be applied to both acoustic trawl surveys and to ordinary surveys for fish,

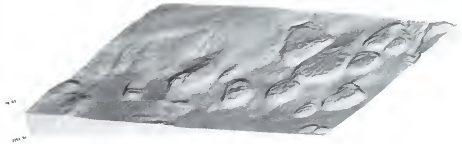


Figure 2.12 3-D Bathymetric Image Derived from Acoustic Data

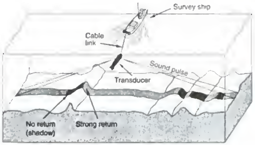


Figure 2.13 The Main Components of a Sidescan SONAR System (after Robinson et al, 1995)

planktons and various water qualitative factors. Since the acoustic data gathered will only represent a sample of the number of fish present, then if this sample is to be used to make estimates of a total population, it is important that the survey transects occupy times or locations such that the information finally produced will have statistical reliability, i.e. it will be unbiased. Track-line patterns used during a survey could take several forms as illustrated in Figure 2.14. As an example of bias in a survey, then if the survey were to follow the zig-zag pattern it is clear that there is a higher sampling intensity near the turns compared to other parts of the track-line. There are several ways of ensuring that bias is minimised e.g. see Williamson (1982),

Francis (1985), Simmonds et al (1992) and Hansson (1993). In an acoustic survey of anchovies off South Africa, Jolly and Hampton (1990) suggested that discrete transects placed quasi-randomly within previously defined stratum areas would give unbiased results (Figure 2.15), though Francis (1985) suggested that simply placing the transects uniformly in parallel lines would still give valid results. Whichever locational method is adopted, it is clear that consideration would also need to be given to factors such as the length of the transects, the time employed in terms of tow length, clock time and time of year, standardisation of all procedures used, etc.

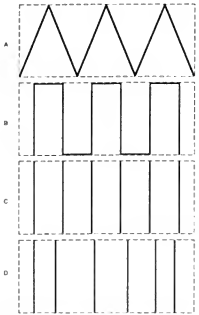


Figure 2.14 Possible Transect Patterns for Use in Trawl Surveys

2.3.4.2 Satellite Remote Sensing Systems

Like acoustic surveys, aerial remote sensing (RS) is concerned with the collection of data by sensing devices which are not in contact with the object being sensed. Various technological developments had become integrated to the extent that satellite observations from space first became feasible in the 1960's. Since that time several series of satellites have been launched,

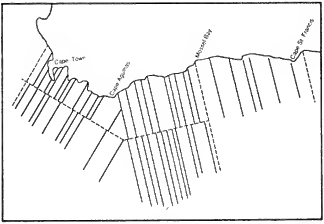


Figure 2.15 Transect Plan for an Acoustic Survey Off South Africa Using Quasi-Randomly Generated Track-Lines (after Jolly and Hampton, 1990)

first by the Americans and Russians, and more recently by France, a European consortium (the European Space Agency - ESA), plus India and Japan. Generally, the equipment used has become progressively more sophisticated enabling a greater range of images to be captured in a more detailed spatial resolution. This in turn has led to a greater utility of RS as a viable data gathering medium. Figure 2.16 shows the main satellite RS systems which might provide directly useful data for a marine fishery resources GIS. From this it can be seen that the main marine parameters which can be monitored relate to water temperatures, wave height and direction, bathymetry, ocean currents and water colour, though indications can be estimated for sediment concentrations, phytoplankton standing stock, turbidity patterns, current speed and direction and light attenuation coefficients. Figure 2.17 gives a simple illustration of how useful RS could be to fisheries resources management. These satellite images show the plankton densities for one time period in the upwellings off the coast of (a) Peru and (b) West Africa. Red and yellow equals dense blooms, darker blues are areas having almost no plankton and black is the land. It is interesting to contrast the coastal areas in Peru where the upwelling occurs with those having no upwelling and thus no plankton. Recent work has also shown that, in cases where water quality is good, then it is possible to use RS to differentiate between certain sea bottom types (Luczkovich et al, 1993). For additional information on how satellite RS techniques have been used to aid marine fisheries see Hock (1986), European Space Agency (1987), Butler et al (1988), Myers and Hick (1990), Allan (1992), Cusido et al (1992), Simpson (1992) and Prasad and Haedrich (1993).

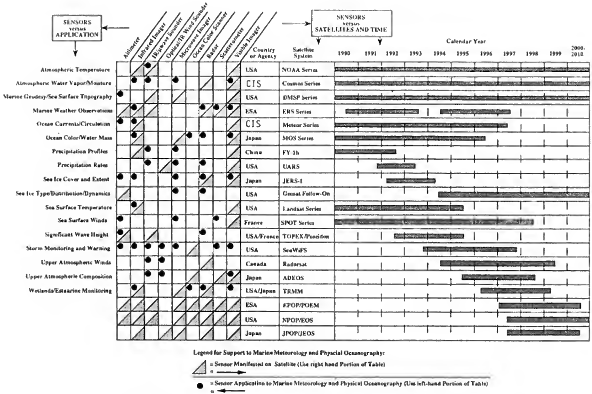


Figure 2.16 Current and Planned Satellite Systems in Support of Marine Meteorology and Oceanography - 1990 to 2010 (from UNESCO, 1992)

For its functionality satellite RS relies upon several pieces of hardware:

(a) A satellite which is in space either in a geo-stationary orbit or it is earth orbiting. This is the platform for:

(b) Various sensors, which gather certain wavelengths of electromagnetic radiation (EMR) given off from the earth. The variable amounts of radiation detected must be relayed back to:

(c) Ground control centres which control the RS activity and produce RS output data. The relaying of data from the satellite is achieved by:

(d) Data storage and transmitting devices on board the satellite.

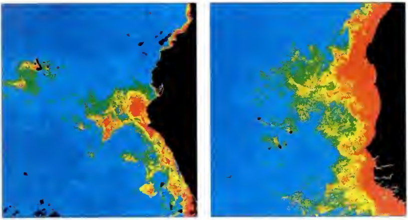


Figure 2.17 Processed Satellite Imagery Showing Plankton Densities Off Peru (left) and West Africa (right)

So RS relies on the fact that different facets of the earth's land or water surfaces transmit or reflect different amounts of energy, i.e. they have so called spectral signatures as shown in Figure 2.18. The sensors detecting EMR may be either push broom (framing), in which case an entire image is captured instantaneously (as in still photography), or scanning in which case the sensor sweeps across a scene in a series of parallel lines collecting data, via numerous detectors, to build up an image (Figure 2.19). Each detector records a value, using 8-bit coding to give a possible range of 256 values corresponding to emitted radiation, for each square on the earth's surface, and the size of these individual picture elements (pixels) denotes the sensor's

resolution. The sensor's resolution is a function of the height of the satellite, the focal length of the lens, the wavelength of the radiation and other characteristics of the sensor itself. The use of different spectral bands produces different EMR values. There are so-called passive sensors, which record reflected or emitted EMR, or active sensors which illuminate an object with their own radiation source and then record the echo, e.g. the underwater acoustic devices as discussed above would be active sensors.

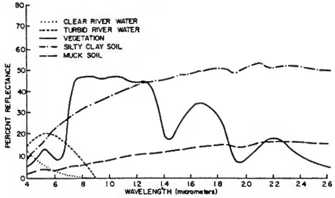


Figure 2.18 Spectral Signatures of Various Natural Earth Features

Satellites may be classified as being either "geostationary" or "polar orbiting" (Figure 2.20). The geo-stationary satellites circle the earth at a height of 35 900 kms usually above the equator. At this height their speed of travel can be easily matched to the speed of the earth's rotation. These satellites, though having a poor spatial resolution of between 2 and 5 kms, are useful for telecommunications, for transmitting real time views of the earth's weather and for monitoring certain environmental factors. Geo-stationary satellites include the GOES and Meteosat series plus India's INSAT and the Japanese HIMAWARI.

Most orbiting satellites are in near polar orbits at heights varying from 270 to 1600 kms, and they complete a revolution of the earth in 95 to 115 minutes, i.e. 12 to 16 revolutions per day (see Figure 2.23). By far the most productive satellites, from the point of view of total data available, have been the U.S.A. Landsat series, using their Thematic Mapper and Multispectral Scanner sensors (Figure 2.21), and the two French SPOT satellites. Both systems have been used for "mapping" vegetation, geological features, soil types, various linear features such as larger rivers and certain water parameters. The SPOT satellite is capable of producing 3-D images through its ability for "off-nadir" viewing at angles of up to 27 degrees (Figure 2.22). There is now a huge amount of imagery available from the Russian Kosmos series of satellites. Most of this imagery has been obtained by short life (11 to 31 days) satellites which have on board

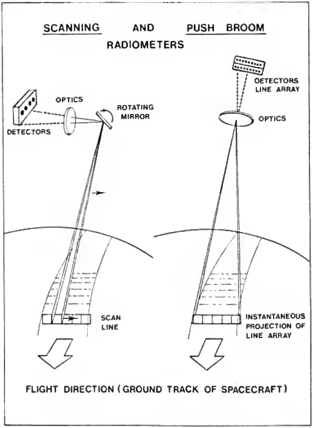


Figure 2.19 Geostationary and Polar Orbiting Satellite Positioning

framing camera sensors - these take high resolution photographs which are physically returned to earth for all processing. Of special importance to any marine GIS is the European Space Agency's (ESA) ERS-1 satellite, i.e. since its sensors have been designed with a view to obtaining important data relative to seas and oceans including characterisation of ice fields, spectral analysis of surface waves, mapping of surface wind fields and the measurement of sea surface temperatures. Figure 2.23 shows the polar orbital tracks for ERS-1 during one 24 hour period plus the data gained on wind speed (in miles per second). In approximately 80 hours wind

patterns for the whole global marine area can be mapped. It is then possible to derive a mean wind fields for any area (Figure 2.24). Data for the compilation of this is based on recording changes in the backscatter of the sea surface every 3.763 seconds. Figure 2.25 shows the data gathering characteristics of some ERS-1 sensors. Thus the main sensor aboard is the Active Microwave Instrument (AMI) which can operate in image mode for capturing certain data (see Figure 2.25 (A)), or wave mode (B).

The electronic images which have been captured by the sensors are either transmitted as a stream of binary numbers directly to the ground receiving stations or are stored in on-board recorders for later transmission. At this stage the data is in a pre-processed state. To make the data useful for GIS purposes there are an array of image analysis processes which can be performed. The most important of these are reviewed in Chapter 4.

There are a wide range of future satellite missions presently being planned, most of which were shown in Figure 2.16. ESA has three projects at present, i.e. ERS-2, ENVISAT and METOP which will provide a continuous environmentally biased data-stream until 2009. The US plans to launch many satellites over a similar period, including Landsat-7 and further satellites in the Tiros/NOAA series, and France, India, Japan and Russia will continue with their polar and/or geo-stationary platforms. A new trend in the US is that for the first time private companies will be launching their own satellites with an obvious view to making profits from data sales, and at least one US sensor, to be launched by Lockheed in 1996, is planned to have one metre resolution which will give the GIS user a viable alternative to aerial photography. More ground receiving stations worldwide will also be commissioned which will aid the consistency of image supply. A further important future trend is for the building of lightweight satellites (750 kilos) for placing in low orbit. This will have the effect of considerably reducing costs, especially those of launching.

It is also of interest to mention here that several private companies have recently negotiated commercial deals with private fishing vessels, to supply them directly with up-to-date (near real time) transmitted satellite data, which are made up by combining images showing water colour conditions and sea water surface temperatures. These charts can prove very useful in suggesting where pelagic concentrations are likely to occur. The images are transmitted via the Inmarsat communications satellite and can be displayed on a personal computer.

Before completing this brief look at remote sensing it is important to mention a few of the limitations which are inherent in this technology. We do this because in many senses RS has not achieved the potential which many expected of it. Thus, although the progress in RS technology and applications has indeed been vast, and GIS is proving to be a valid medium for propagation of RS data, the data provided by this methodology is far from easy to use. Some of the main limitations include:

(i) Cost. Table 3.4 gives some indication of recent RS data costs, and Figure 2.26 gives a comparison of SPOT imagery costs with aerial survey costs as a means of updating 1:10 000 digital base mapping in New Brunswick, Canada (from Rapatz et al, 1990). These costs show

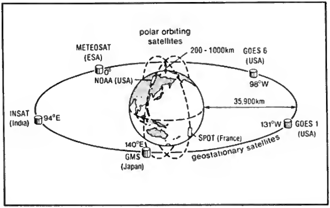


Figure 2.20 Basic Principles of Scanning and Push Broom Satellite Remote Sensing

that if the one SPOT image can be used for updating up to 80 map sheets then costs are very competitive, though the authors caution on what the mapping priorities might be. Thus, although in terms of cost per square kilometre of surface imaged the prices might be good value, each image only represents one moment in time and several images may be needed to cover a fairly small oceanic or coastal area. There are also large image processing costs to consider.

(ii) Lack of images. Because cloud cover duration varies greatly from area to area, the number of images available for nearly contiguous areas can vary by a factor of five. So equatorial regions, west facing coastal areas in the mid to high latitudes and areas having seasonal rainfall may have a paucity of data. Also, data is scarce for polar areas and areas beyond the receiving range of some satellite transmitters.

(iii) Ground truthing. Since there is no way of being certain that the EMR value recorded for a pixel represents a particular land use or water condition, then it is essential that the imagery is verified by on-ground verification. This is also inconvenient in that it needs to be done at the same time as the satellite pass occurs, i.e. since pixel values can change from day to day.

(iv) Spatial resolution. The best resolution generally available from satellite RS is 10 metres, although much of the Russian satellite photographic data is down to 2m resolution. Whilst this range of resolution is suitable for many purposes, it is clear that smaller objects cannot be detected. The technology exists to get better resolution. When the political, cost and legal barriers to its acquisition are overcome, then RS should prove much more useful.

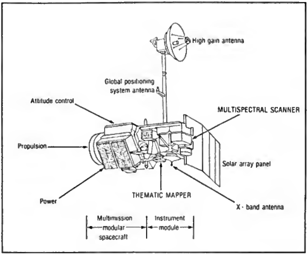


Figure 2.21 The Configuration of Landsats 4 and 5

(v) Long term planning and payload uncertainty. Most longer term projects using RS data require an assured temporal sequence of images, partly in order to justify the necessary hard and software costs. To some extent RS suffers from "planning blight" in that most satellite launches have suffered from uncertainty in scheduling and payload. Delays, such as the three year hold-up on ERS-1, have been mostly caused by lack of funding assurances and technological problems.

(vi) There are many other minor problems such as the vast data storage capacity needed, obtaining the necessary skills for RS imagery interpretation, plus the actual management and upkeep of the data.

Notwithstanding these problems, we envisage that the longer term future for RS is very healthy, especially if the GIS and RS technologies continue to become better integrated. The following list illustrates some reasons for our optimism:

(a) There are a large number of planned and committed satellite launches. Some of these are joint satellite ventures between different countries.
(b) RS is being utilised in an increasing number of fields.
(c) It is increasingly easy to be able to integrate RS imagery into GIS programs.
(d) There is some evidence that the technology behind the defence uses of RS will be increasingly diverted to civilian use.

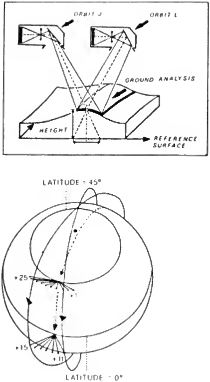


Figure 2.22 Stereoscopic Viewing Capabilities of the SPOT Satellites

(e) RS is undoubtedly likely to play an increasing role in the move towards environmental awareness.

(f) Rapid advances in processing hardware means that the vast data increases provided by RS will be relatively easily handled.

(g) New types of sensor platforms are being developed which will eventually ensure a wider variety of sensors can function and that they can be serviced in orbit.

(h) A Number of new countries are entering the satellite RS field, e.g. Canada, China, Brazil and Indonesia - they will require some return on their expensive investments.

(i) The larger number of radar (active) sensors now airborne or planned will ensure better data coverage from areas having cloud cover problems.

(j) Future imagery capture is likely to be programmable to specific user requirements.

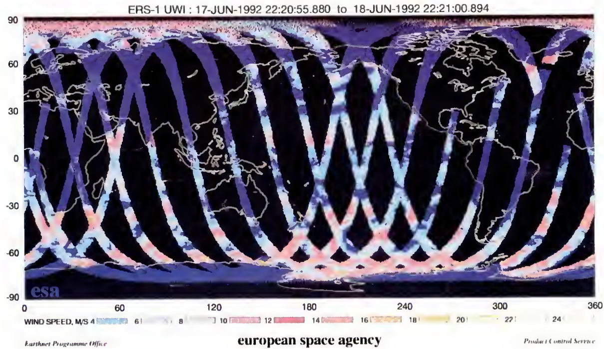
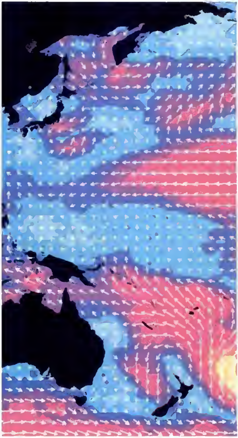


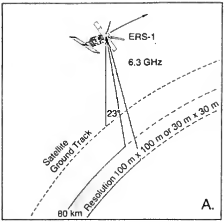
Figure 2.23 Orbital Sequence and Colour Coded Chart of Ocean Surface Wind Speeds Collected on 18th June, 1992 by the ERS-1 Satellite



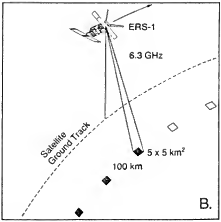
A wind field map of the western Pacific Ocean produced from Seasat Scatterometer data. Arrows show wind velocity, which is colour coded for emphasis: blue < 4 m/s, yellow > 14 m/s, land is shown in black.

Figure 2.24 Composite Wind Field Map of the Western Pacific Compiled from Wind Scatterometer Data Collected by the ERS-1 Satellite

(k) RS is the only means by which an instant synoptic view can be obtained of areas varying from a 60 x 60 km cell to a whole earth disk image.



Technical characteristics of the AMI SAR Image Mode
Image Mode: When operating in the image mode the AMI performs as a synthetic aperture radar (SAR) producing high quality wide swath imaging over ocean, coastal zones and land.



Technical characteristies of the AMI Wave Seatterometer
Wave Mode: When operating in wave mode, the instrument will measure the change in radar reflectivity of the sea surface due to the ocean surface waves.

Characteristics of the AMI-SAR; Image and Wave Mode.

Parameter	SAR Image Mode	SAR Wave Mode
Frequency	5.3 GHz	5.3 GHz
Polarisation	vv	vv
Pulselength	37.1 μs	12.3 μs
Incidence Angle	23 degrees	23 degrees
Swath width	80-100 km	5.0 km
Spatial resolution (8 look averaging)	< 30 m	< 30 m
Radiometric resolution	2.5 dB	2.5 dB
Initial Repeat Cycle	3 days	3 days

C.

Figure 2.25 Technical Characteristics of the ERS-1 Active Microwave Instrument Operating in (A) Image Mode and (B) Wave Mode

(l) The capability that RS has to undertake repetitive coverage so as to achieve temporal monitoring of any area or circumstance.

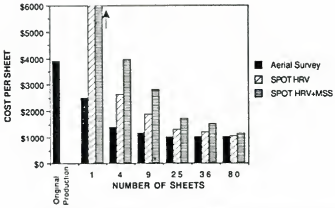


Figure 2.26 Cost Comparisons for Map Revision in Canada Using Three Different Data Sources

2.3.4.3 Aerial Photography

Since the middle of World War 1, photography from aircraft has been used as a method of obtaining spatial information, and since then there have been many advances which have ensured that nowadays aerial imagery is of a very high standard. Flight programmes for mapping purposes must be flown within the parameters as shown in Figure 2.27, i.e. such that large overlaps are obtained. The overlaps are necessary in order that stereoscopic (3-D) viewing can take place. Until the mid 1980's most aerial photography was accomplished in black and white using panchromatic or infrared film, but with the development of high resolution colour film and cheaper processing techniques then colour output became the norm. Recently however, to avoid the need to convert an aerial photograph into a digital form for input to a GIS, digital cameras have been developed, i.e. which capture images directly as arrays of coded pixels. These cameras can be adjusted to record different spectral bands within the visible and infrared spectrum. Aerial photography as an aid to GIS has advantages over the use of mapping in the sense that more detail can be obtained on existing land use or on sea-based activities, and it may be preferable to satellite RS because of the much higher resolution obtainable and the fact that specific flight programmes can easily be arranged. Imagery is typically available at scales between 1:2 000 and 1:25 000.

The extraction of valuable information from aerial photography depends on the process of photogrammetry. It will be clear that when any in-flight photograph is made there could be many sources of image distortion (Figure 2.28). To correct for these a stereo plotter is used. This

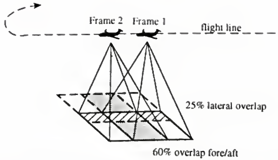


Figure 2.27 Image Overlap Sequence for Attaining Stereoscopic Aerial Photography

device allows an operator to view two overlapping photographs, taken from different positions, in order to form a three dimensional image. The operator can then draw in any desired outlines in their correct location. Using digital photogrammetric techniques all lines and objects in the drawing can be numerically encoded and stored in a computer database. In many areas of the world, original topographic mapping is being done via photogrammetric techniques. It will be appreciated that an accurate orthophoto, i.e. one that has been corrected to remove the distortions, will form an excellent basis upon which to ensure the accuracy of mapping. The interpretation of aerial photographs is a highly skilled task, one that is explained in detail in Star and Estes (1990).

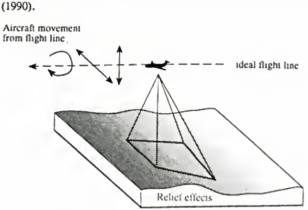


Figure 2.28 Some Sources of Error in Aerial Photography

With the likely increased use of aerial surveillance methods for monitoring fishery activities, then a particular aerial data collection system which will be worthy of future consideration is the use of airborne videography, i.e. the use of a simple video recording camera from an aircraft with its potential for the digital processing of the electronic signal (Figure 2.29). Debusschere et al (1992) and Mausel et al (1992) provide further details on this methodology. A similar digital remote sensing data capture method from aircraft is reported by Borstad et al (1992). They have used successfully a Compact Airborne Spectrographic Imager (CASI) to directly capture the spectral signature of schools of Pacific herring (Clupea harengus pallasi) in shallow waters off the coast of Canada.

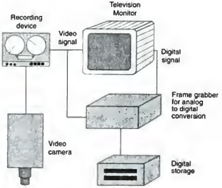


Figure 2.29 The Main Components of a Videographic Image Collection System (from Robinson et al, 1995)

CHAPTER 3 - THE ACQUISITION OF SECONDARY DATA FOR A MARINE FISHERIES RESOURCE GIS

3.1 Introduction

All secondary data represents primary data which has been converted into a more accessible and processed form. The variety and sources of secondary data is huge, and Table 2.1 briefly indicated this. From the marine fisheries viewpoint, Table 3.1 is an attempt to show the types of data and data sets which may be available. Obviously this table is not exhaustive and it would be possible to have numerous sub-categories of each. All of these sources are held in hardcopy format and many of them are now available in digital or film form as well. Some of the data is clearly in mapped or graphical form, other is textual and the remainder may be tabular. We would caution readers that actual access to secondary data varies greatly from country to country, i.e. some countries such as the USA consider most data which has been collected by the government as being in the public domain, and there are few barriers to its access. Most other countries consider data as belonging to the agency that collected it, and access to it may be strictly controlled. As a result of the diversity of marine related data sets, there have been attempts at various levels to ensure the standardization and maintenance of data sets. Table 3.2 gives useful examples of some organizations responsible for collecting marine data.

Table 3.1 Types of Marine Data and Data Sets (after Townsend, 1991)

1. Ocean biological samples
2. Geological collections of seabed rocks and sediments
3. Current measurements
4. Echo sounding profiles
5. Seismic records
6. Sidescan sonar records
7. Magnetic records
8. Gravity records
9. Earth tide data
10. Plankton records
11. Inter-tidal biological records
12. Sea surface temperature
13. Frequency and location of sea mammals
14. Fisheries data
15. Wind data
16. Bathymetric data
17. Conductivity data
18. Salinity

Table 3.2 Some International Organizations Responsible for Collecting Marine Data

1. National organizations such as NOAA (National Oceanographic and Atmospheric Administration of the USA) and NERC (the Natural Environment Research Council of the UK).
2. International Oceanographic Commission's (IOC) Working Committee on International Oceanographic Data Exchange (IODE)* which has set up:
   (a) a group on format development leading to a general Formatting System for Geo-referenced Data (GF3)
   (b) National Oceanographic Data Centres (NODC) including Responsible NODC's (RNODC) with responsibilities for specific data sets for the international community. For example, the UK NODC is called MIAS (Marine Information Advisory Service) and has particular responsibility for world waves.
3. International Gravity Bureau at Toulouse.
4. General Bathymetric Chart of the Oceans (GEBCO) under the International Oceanographic Commission and the IHO.
5. FAO Fishery Data Centre in Rome.
6. Major international programmes such as WOCE (World Ocean Climate Experiment), JASIN, IGY.
7. Regional organizations such as the International Council for the Exploration of the Sea (ICES).

* Subsequently renamed the IOC Technical Committee on International Oceanographic Data and Information Exchange (though retaining the same acronym).

There are several trends and problems which are in evidence regarding secondary data sources. A major trend is the exponential growth rate of many of the published information and data sources, e.g. especially academic and trade journals, topographic maps, conference proceedings and CD-ROMS. To help access this data, which traditionally has been sought in hardcopy abstracts and bibliographies, there have developed first microfiches and more recently CD-ROM databases and computer "on-line" networking facilities. The problem with obtaining secondary data via networking, is simply the sheer volume available and therefore the difficulty of finding exactly the data required. In section 3.4 this is examined in more detail. Searching for data is theoretically becoming easier with the "on-line" electronic search facilities in many of the larger libraries, universities, research facilities or government offices. These give instant access to the resources held within the institution or they provide references to particular subject areas which may be of interest. The problems associated with on-line facilities are that they are sometimes difficult or expensive to access and, once having found a quoted reference or abstract, it can take some time to obtain a full copy. There is also a trend towards publication in the English language and a move towards more subject specialisation.

In the main secondary data which may be relevant to GIS's can best be examined under three headings (i) mapped, (ii) tabular and (iii) digital data.

3.2 Secondary Maps and Their Sources

Existing mapped information has undoubtedly been the major source of data for most GIS initiatives. This obviously results from the fact that the very essence of GIS is concerned with spatial allocation considerations, the subject of which best lends itself to various forms of mapping. Space precludes any consideration of the importance or methodology of mapping per se - interested readers should consult Muehrcke (1986), Butler et al (1987), Monmonier (1993) or Robinson et al (1995). Here we shall simply describe the main types of maps available, and potentially useful for a marine fishery resources GIS, and then suggest some of the sources for obtaining these. Whilst our discussion will be in terms of hardcopy maps, it is essential to mention that a large proportion of mapping being produced by government agencies in developed countries may also be acquired in digital format. Obviously this is extremely useful from the GIS viewpoint, and so digital data sources are examined in section 3.4.3. For convenience we can categorise maps as being of three main types -hydrographic, topographic and thematic.

3.2.1 Hydrographic Maps and Charts

Most countries having direct access to a sea or ocean coastline produce hydrographic maps. These are maps which typically show the coastline, bathymetry, isolated depth soundings, obstacles, navigation buoys and lights and other relevant navigational information. They are usually produced by some maritime authority or the official government mapping agency. The scale of the maps varies from 1:50 000 upwards to 1:10 000 000, though for port areas more detailed sheets are available. All standards for world sea mapping are regulated by the International Hydrographic Organisation.

As an example, the Hydrographic Office (HO) in Britain publishes 3 300 sheets of the world-wide Admiralty Chart series. These are the authorative source of navigation information for many countries which might not produce their own maps. These maps are kept constantly up-to-date. The HO also produce many other map series which might form a valid input to a GIS, such as tidal charts and the 74 volumes of the "Sailing Directions" which describes all the world's coastlines. HO maps are available from a network of chart agents located in most major ports.

Another series of hydrographic charts which are specifically compiled for use by fishermen are the Kingfisher Charts. These cover all British waters, plus the North Sea, Irish waters and some French and Icelandic waters. These maps give detailed depth information plus the position of wrecks, cables, pipelines, wellheads and other obstructions. They also show seabottom types. Obviously they are particularly useful in planning bottom trawls. They may be obtained from the company headquarters in England plus many overseas agents. Sea bed sediments and bathymetry can also be obtained from the British Geological Survey 1:250 000 Sheets covering 1 degree of latitude x 1 degree of longitude for all British coastal waters.

3.2.2 Topographic Maps

These are the typical product from most national mapping agencies. They aim to portray and identify important features of the earth using levels of accuracy which are consistent with the scale of the map. They are usually produced in a series which covers a whole country. Topographic mapping will be by different scales which may be classified as follows:

Large scale	1:1 250 to 1:25 000.
Medium scale	>1:25 000 to 1:200 000.
Small scale	>1:200 000.

All topographic maps have clearly defined keys, scales, direction indicators, a grid/co-ordinate system and many will be in colour. The individual features shown on maps will be a function of the map scale.

The world coverage by topographic mapping varies considerably from region to region and it is impossible to give precise details on this since in many countries topographic maps are confidential at certain scales whilst in some countries the actual quality of mapping is so poor, or the content is so dated, that the map may not be worth having, certainly for GIS purposes. Generally map availability is relative to a country's wealth or degree of development. Thus in Europe, North America and Australia, mapping at a scale of 1:250 000 or smaller is complete, and in most areas maps at a scale of 1:50 000 are available. In most parts of Africa, Asia or South and Central America detailed mapping (I:50 000 or larger) may only be available for urban areas; indeed Butler et al (1987) estimated that perhaps 42% of the world is mapped at this scale. There is no doubt that RS capability is allowing the rate of world topographic map coverage to speed up, but there is unlikely to be total coverage at a scale larger than 1:100 000 by the end of this century.

In acquiring topographic maps as a data source for GIS, the user should be aware of some potential problems. Many countries cannot afford expensive revisions so many surveys may be at least twenty five years old. Maling (1989) has highlighted the general problem of inaccuracy, i.e. when comparing an RS image with a topographic map for the same area, and Parry and Perkins (1987) outline those areas where maps may be impossible to acquire. Every country will have its own spatial inventory processes, preferences and standards and the interested map user will need to find out these to his or her own satisfaction. Before acquiring topographic hard-copy maps for GIS purposes, the GIS user should consult the mapping agencies to ascertain whether the maps are available in digital format, and what date the most recent editions were published.

3.2.3 Thematic Maps

As maps have become increasingly complex, then sub-sets of the original information have been more frequently displayed. Since these maps invariably concentrate upon one topic they have become known as thematic maps. There would be an almost limitless number of thematic maps because the themes themselves are endless, and in view of the fact that there are far more scale

variations among thematic maps than with topographic maps. Thematic maps frequently use topographic maps as their outline source and in fact much of the basic map detail might be retained. Figure 3.1 shows a typical thematic marine related map. Many thematic maps may abandon some of the basic principles of topographic accuracy in order to highlight some specific theme. So for instance, in a typical route map, spatial accuracy will often give way so as to produce a straight line along which places (or other features) are placed in their correct order with distances between each being written in.

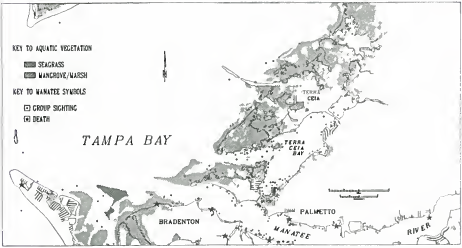


Figure 3.1 **Example of a Marine Thematic Map Showing the Distribution of Manatees and Their Habitat in Southern Florida, USA**

Undoubtedly there is a move towards the publication of more and more thematic maps. This has evolved out the growing recognition of the usefulness of maps, the fact that an increasing number of specialised publications include maps amongst their illustrations, that there is increasing spatial planning activities at all scales and to the fact that computer graphics (and GIS) has allowed for an explosion of digitally produced thematic maps. Thematic maps may therefore be produced in a huge variety of scales, they may vary considerably in there physical size and they may be found in leaflets, books, atlases, promotional material or in a variety of specialist publications. Although there is no universally accepted classification of thematic maps, Figure 3.2 shows and describes some of the major types which are easily identifiable, i.e. by method of cartographic representation.

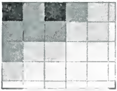
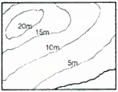
Mapping Type	Characteristics
* *Chorochromatic.* 	These show non-quantitative surface distributions of any feature, e.g. a map showing sea bed variations would show areas of mud, of rock, of sand, etc. These maps can have a huge range of classes with a different colour or range of shading for each.
* *Choropleth.* 	These are quantitative maps which depict average values of some feature per unit of area, e.g. a population density map. A maximum of about seven classes is used and shading is from dark (high density) to light (low density).
* *Isopleth.* 	Isopleths are lines which join places having an equal value. So a bathymetric map is an isopleth map since it shows lines which join places having equal depth below sea level. Other common isopleths include isotherms, temperatures), isobars (air pressure), isohalines (salinity), though there are many other possibilities.
* *Punctiformal.* 	Maps that show point distributions are punctiformal. Thus the location of any individual objects can clearly be mapped with the representation appearing as simple dots, or as some pictorial symbol or shape. Obviously, what can be mapped as a dot on a small scale map might not be punctiformal on a large scale map.
* *Linear.* 	Many features show linear distributions, e.g. rivers, fences, roads, railways, sea routes, etc. Most linear maps simply show the lines followed by a feature, but they can also be volumetric by making the width of the line proportional to say the volume of traffic using a particular routeway.

Figure 3.2 Some of the Major Types of Thematic Mapping

The ease of actually acquiring any of the hardcopy topographic or thematic maps will vary tremendously, largely as a function of where you live and what you are seeking. Nearly all countries have their own national mapping agencies who supply maps to a range of retailers. These retailers typically keep a range of the more popular maps in stock, usually having maps at several scales of the local area, and they will order more specialised maps to customer requirements. It is now becoming possible in some countries to get larger scale local plans digitally printed at the map retail agency, on a "while you wait" basis, covering the exact aerial extent preferred. Many public libraries will keep reference copies of most local maps. There are a number of major commercial mapping companies who publish high quality maps and atlases, e.g. Bartholomews, Geographica, Hallwag, Michelin, Oxford University Press, Philip's and Rand McNally. These companies usually supply detailed catalogues. Many local and national government departments produce a range of thematic maps which are often very detailed, though of variable dates. In some countries there are national map libraries, such as British Library in London which has a collection of more than 1.5 million maps, or there are specialist map shops in the major cities. A visit to any of these sources frequently results in the potential user being pointed in the right direction!

3.3 Tabular Data Sources

Here we shall be briefly concerned with that hardcopy data, which exists in numerous tabular forms, usually consisting of a mixture of aggregated numeric and textual data which has been collected and presented in some logical and cohesive format to satisfy any one of a number of requirements. The presentation formats may vary enormously, from simple one off tables to huge volumes of collated forms. Most tabular data is the type of information which is increasingly being kept on computer databases.

In the author's experience gathering tabular data can be a very frustrating task. Thus, although in most countries there are vast amounts of data, actually acquiring that which is useful or desirable is fraught with problems. So, for instance, much of the data will be classified as confidential, or it can only be released to the general public either after a long time period or with the given permission of certain levels of authority. Many of the records are incomplete or outdated or of dubious levels of accuracy. Much of it may be stored in distant archives or, although it should exist, it cannot be located. Many organisations are even uncertain of the data that they might hold. Also, to be of any value to a GIS, there must be some form of geo-referencing. Frequently this is missing or the levels of dis-aggregation are so poor that it is valueless for any spatially based exercises. So the collection of tabular data will usually involve a large amount of patience and a good measure of discrimination as to its real value. We suggest an approach to collection which encapsulates diligent and polite persistence, though in most cases we envisage that existing tabular data should be ignored, and the user would be advised either to seek existing digital databases and/or to set up purposefully designed data collecting systems. Table 3.3 attempts to outline some types of authorities who may be able to provide tabular data useful to a marine fishery resources GIS.

Table 3.3 Some Potential Holders of Marine Oriented Tabular Data

* Census offices
* Fisheries authorities
* Fisheries research institutes
* Regional fisheries bodies, e.g. ICES, CECAF, GFCM, etc
* University - biology, marine, or fisheries departments
* Fish marketing authorities
* Transport authorities
* Fishery product producers
* Environmental agencies
* Local or regional planning authorities
* Harbour or port authorities
* Hydrographic institutes, e.g. the International Hydrographic Organisation
* Meteorological offices
* International institutions, e.g. World Bank, FAO,UNEP, etc
* Government agencies
* Trade associations or directories
* National oceanographic data centres, e.g. the Marine Information Advisory Service
* Major international programmes, e.g. the World Ocean Climate Experiment (WOCE)

3.4 Digital Data Sources

As we showed in sections 2.3.3 and 2.3.4, a large amount of data is now being collected that is put directly into a digital format, i.e. so that it is potentially of immediate use in a GIS, and vast amounts of data has already been converted to digital formats. It is important to mention initially, that the utility of much of this data varies depending on the data models, structures and standards that have been applied. Before using acquired digital data it is as well to check on its utility and reliability first. Theoretically, this should be possible to do via the meta database kept by the digital data source provider (see section 4.4). Since the range of digital data is so vast we can only illustrate prospective lines of enquiry which show where some of it may be obtained.

3.4.1 Networking

Although it is obvious that any GIS is likely to require huge amounts of digital data, possibly of many different types and from many different sources, and there has long been the recognition that the thousands of existing databases could prove to be of value to many GIS users, until recently there have been few moves to initiate cataloguing systems which can expedite the locating of suitable databases. So the chances of ever finding out whether desired databases were already in existence has largely relied on chance or word of mouth. However, given the rapid growth in all aspects of computer information technology, and especially in light of the capacity of the latest technology to handle vast amounts of data, and of the recognition that data gathering costs will now greatly exceed likely systems costs, specialised data information networks are now appearing. Most of these are presently confined to a relatively few

developed countries, but databases are rapidly becoming accessible world wide through the growth in electronic networking. In this section we will describe the sorts of databases and types of services which might be available, by giving some case studies within some countries who very actively operate database networking facilities. For readers wishing to find out more on electronic databases available, the charging or pricing systems, or on networking generally we recommend Kehoe (1992), Krol (1992), Newton, et al (1992), Rose (1993), Dern (1993), Hahn and Stout (1994) and Bostock (1994).

A "network" here is essentially when two or more computers are linked together to facilitate data or information exchanges. Although computers can be linked within a building on a Local Area Network (LAN), most "networking" is carried out over Wide Area Networks (WAN's) using either existing telephone lines or dedicated data lines. Chapter 5 gives more details on these networks. Both local and wide area networks may have access (or "gateways") to considerable volumes of data which are not held within a corporation. Thus in many countries (and internationally) a number of electronic networks have been established which specifically allow for instant communications and data transfer between computer users in distant locations. Some networks operate within a country, e.g. JANET (Joint Academic NETwork in the UK), though they all have international access through the International Packet Switch Stream network. On the international scale the dominant network is the Internet. This is in fact a conglomeration of computer communication networks that manages, despite its complexity, to present a uniform face to its community. The Internet has its backbone in the USA. It was originally intended for the use of research or academic personnel, but it now has connections to government agencies, private corporations, libraries etc, plus the general public. Although local connection charges may be made, the actual usage time on the network is free. The total number of Internet users worldwide was about 25 million in 1994, with growth having doubled over each of the previous two years.

To gain access to the network, users or institutions require a leased (or dial-up) telephone line, a MOdulator/DEModulator (MODEM) and a computer with an appropriate communication interface (Figure 3.3. Users must also have their own identification code. It can be seen that a modem is the essential piece of hardware for networking and thus for obtaining access to remote databases. Modems are basically devices which allow for the connection between computers located in separate places. They may be either of a fixed, permanent type (direct connect modems), or an acoustic coupler modem which allows for an ordinary telephone handset to be placed in the modem so that data transmission can occur when required.

For networking, and therefore electronic data transference, to expand there are a number of technical obstacles which are presently having to be faced and surmounted: (a) Standards. The growing "global information technology industry" will be totally dependent for its long term future on internationally agreed standards for hard and software components and for data exchange systems.

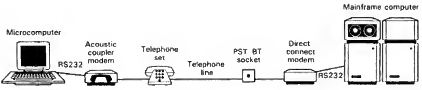


Figure 3.3 Communications Between User and Database via a MODEM and Network (from Maguire, 1989)

(b) Data coding. It is essential that universally accepted data coding systems are adopted so as to minimise the expensive and time consuming tasks of transmitting data.

(c) Telecommunication methods. The conventional telephone lines were designed for voice transmission. A set of new standards has now been introduced called Integrated Services Digital Network (IDSN), which replaces the old lines with a single information pipeline, and other standardised equipment, so that all of the world's telephones may eventually be capable of being linked interactively.

(d) The introduction of fibre optic transmission lines which are capable of transmitting far more data at a fraction of the cost of metallic cables.

(e) Data compression. For data transfer efficiency, techniques must be introduced which will allow much better data compression ratios than those currently being achieved. Using methods based upon fractal geometry, it is likely that compression ratios may be improved from the present 10:1 to at least 10 000:1.

Given that most of these obstacles are likely to be rapidly overcome, the practical use of networking is certain to grow exponentially. The primary use of much networking to date has been the transference of personal messages via electronic mail (E-Mail), or the pooling of information among persons who join up to specialist "lists", e.g. there are a number of special GIS lists such as EDGIS-L, ESRI-L, COASTGIS-L, CONGIS-L, etc, all of which operate on a world wide basis and through which the user can seek and share information. There are also a number of electronic journals beginning to be set up on the network as a rapid means of spreading the results of academic research. The network is also proving very useful for the almost instantaneous transmission of data files. And it is not only data or information which can be transmitted in this way. There is already evidence that the transmission of the final GIS raster or vector maps will be possible via networking, i.e. now that methods have been found which

allow for the compression of the huge amounts of data involved (Knott and Shiers, 1994). At its present stage of development, perhaps the major problem with the Internet is the fact that there is a vast collection of data to be found, but it may be extremely difficult to find what you are looking for!

3.4.1.1 An Example of Some Canadian Marine Networks

Most of the information in this section is condensed from Butler and LeBlanc (1990) plus personal communications from Butler (1994). This particular example has been selected because the eastern seaboard of Canada appears to be the most advanced area in terms of the implementation of the networking of marine databases. Having the world's longest coastline and 16% of the world's surface area of fresh water, Canada has a long tradition of utilising aquatic resources. However, the eastern seaboard especially is subject to a wide variety of pressures which threaten the development and management of its resources. These pressures come from various agricultural and forestry activities, community and industrial relationships, shipping, dredging, hydro-carbon and mineral extraction, marine resource depletion, plus more broad scale phenomena such as global warming, sea level rising, air pollution and shoreline erosion. To help alleviate the harm caused by some of these pressures, a number of governmental agencies and private organisations have been set up, and there has been a strong recognition that the accumulation and dissemination of data will prove to be a key constituent to success. Having both a comprehensive communications network and a large number of computer literate data users, then the networking of data and information is already proving to be a valuable move forwards, affecting many aspects eastern seaboard community life.

We now briefly describe some of the developments in the major information and data transfer systems which have been, and are still, emerging here. The various networks and information systems all fill slightly different roles and operate at very differing scales, though in many cases there will be overlaps in the services. An umbrella organisation, The Atlantic Coastal Zone Information Steering Committee (ACZISC), now acts as a focus for the development of the information infrastructure, and in 1992 the Committee produced an "Atlantic Coastal Zone Database Directory" which is an aid to promoting the various networks. The directory describes 408 databases which are relevant to Atlantic Canada. Figure 3.4 shows the overall infrastructure of the Atlantic Coastal Zone Information System. The following network list will not describe any of the foreign or international networks which would, of course, also be available within Canada.

(i) Marine Environmental Data Service (MEDS). This was established in 1973 by the Dept. of Fisheries and Oceans (DFO) as a national service for the management and care of oceanographic data, which had been acquired by various means and which applied to Canadian waters. Data is provided by MEDS to the marine community generally, and it includes mainly oceanographic station data, tide and water level data, wave data, drifter data and current meter data. As well as providing raw data MEDS will add value to their data in any user defined way, carry out digitising, advise on where data not held

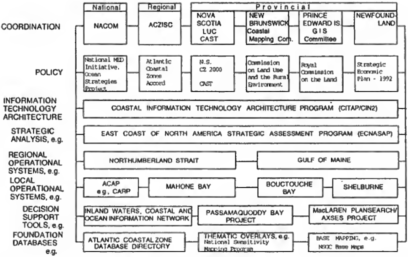


Figure 3.4 The Overall Infrastructure of the Atlantic Coastal Zone Information Management System

by them may be obtained, acquire data from other national systems, etc. Services provided by MEDS are generally free for small jobs and costs are recovered for larger data provision.

(ii) Ocean Information System (DFONET). This system is being set up by the DFO, but it is intended to be much more wide ranging than MEDS. Figure 3.5 schematically illustrates how DFONET functions. In the middle is the network which can be linked locally, nationally or internationally and it can expedite E-mail or data gathering functions. The upper portion of Figure 3.5 shows the information and services available. Most are self explanatory, though the "Distributed Inventory" functions act as a meta database. Note that data flows are two way, i.e. the network is obviously not just considered as a data gathering function. The "Modelling Nodes, Data Generation" ultimately require super-computers to aggregate data and prepare and run models. The lower portion of Figure 3.5 illustrates the anticipated users of the network. Here,

"Broadcast Users" represent, for example, the marine weather forecasting community and "OGD" is other government departments. The Ocean Information System functions under four sub-systems:

(i) data collection and distribution;
(ii) product development and distribution;
(iii) product evaluation and
(iv) research and development.

There are several major ways in which the system is being further developed including the investigation of ways of speeding up communication linkages, the incorporation of ERS-1 satellite data, the development of expert systems (including artificial intelligence), the further development of products and services and they are looking into future super-computing requirements.

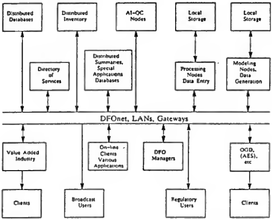


Figure 3.5 **Schematic Representation of the DFO's Ocean Information System (DFONET)**

(iii) Gulf Geographic Information System (G-GIS). This has superceded a previous system known as IFISH/G-GIS. This system integrates a number of databases on fish habitats, the environment and man's activities that impact on fish, fishing and fish habitats in the Gulf of St Lawrence area. It is operated by the DFO at Moncton, New Brunswick, it uses a CARIS GIS and the system is presently being expanded.

(iv) Coastal Ocean Water Level Information System (COWLIS). This system is being developed privately in response to marine shipping, safety and resource management requirements and it integrates the real time telemetering of modern tide gauges into the data network. A central system gathers the tidal data from numerous gauges via modems, and the user can gain access to this data via special COWLIS "Tideview" software operating on a PC.

(v) Foreign Fishery Information System (FFIS). The DFO is responsible for the management of domestic and foreign fishing activities within Canada's 200 mile EEZ. Thus it must plan and supervise surveillance activities, patrol fish and habitat areas, license foreign vessels, inspect fishing activities and monitor vessel movements. To help in this work, the DFO has a networked database system called FLASH which is housed on a mainframe computer at its Toronto headquarters. Data is input daily and the service provides an automatic mechanism for recording information regarding licenses, quotas, catch and effort statistics and the surveillance of foreign vessels.

(vi) Electronic Chart Display and Information System (ECDIS). For several years the International Maritime Organisation and the International Hydrographic Organisation have been developing an electronic chart system, comparable to conventional paper charts, which is called ECDIS (see Huet, 1992 or Smith, 1990 for a summary). Working with satellite GPS and other information systems, ECDIS can show the position, course and track of marine traffic on a computer screen. Figure 3.6 shows a model of the proposed system - ENC is electronic navigational chart, the system is SENC, ECDB is the electronic chart data base and ENCD is the electronic navigational chart data. Trials of the system have been taking place involving Canada and eight European countries plus the Norwegian Hydrographic service vessel M/V "Lance" and, providing that certain conditions are met, access to huge volumes of hydrographic data should soon be available via the network. At a local level the Canadian Hydrographic Service is investigating a complementary electronic chart data base system called POD (Print On Demand).

(vii) Atmospheric Environment Service (AES). This government run service consists of supplying data on a series of inter-related climatic subjects, e.g. marine and coastal meteorological data, time series of extreme climatic data. There are seven systems which currently control each data area, i.e. as well as raw data, the service provides such things as basic statistical summaries, contingency tables for combined probabilities, contour analysis of selected parameters and likely return periods of extreme events. The service can be accessed by users having a special account and the appropriate user manual.

(viii) Similar to the above, but operated by a private company, is the MacLaren Plansearch Weather Information Network System (WINS). For its functionality, WINS relies upon any number of PC's networked to the company's main DEC MicroVax computer. Any of several different weather related data streams can be transmitted via Telesat Canada's Anikom 100 service. Information is received by the client's own satellite dish which may be sited at any location.

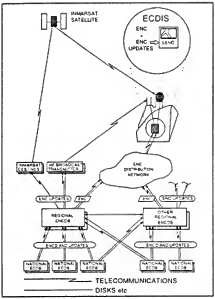


Figure 3.6 Schematic Model of the Electronic Chart Distribution System (ECDIS)

(ix) Ice Data Integration and Analysis System (IDIAS). A private company, MacDonald Dettwiler and Associates, are currently building for the Ice Centre of Environment, Canada, a data system which geo-references, processes and displays an assortment of ice related data. This is mostly with the intention of monitoring sea ice for fishing, hydrocarbon exploitation and navigation interests. Raw data for the system comes from either reconnaissance aircraft carrying various RADAR systems or from NOAA, Landsat and ERS-1 satellite imagery. A range of data products will be available to the networked user. The system's operational and data flow systems are shown in Figure 3.7.

(x) Inland Waters, Coastal and Ocean Information Network (ICOIN). Very recently, this new network has become established on behalf of the DFO. It is based on a series of regional databases, e.g. with an Atlantic ICOIN being set up at the Champlain Institute in Fredericton, New Brunswick. "ICOIN will provide a new information infrastructure, a network of distributed geo-referenced data bases to support environmentally sound sustainable development and management of Canada's oceans and freshwater areas." (Butler and LeBlanc, 1990). The authors state that the idea behind this new network is to have one fully comprehensive data source, with the implication that the current situation in gaining data access is too fragmented in terms of subject areas, accessing rights, standards, quality, etc.

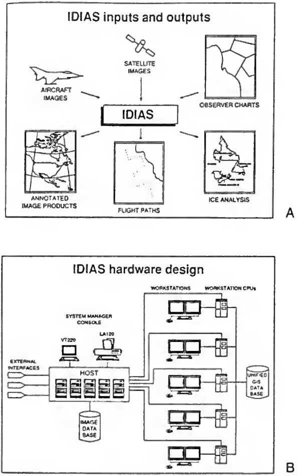


Figure 3.7 Schematic Diagrams Showing data Flow (A) and Operational Configuration (B) of the Ice Data Integration and Analysis System (IDIAS)

(xi) Networked Distributed Environmental Information System Project. This project is a proposal to design and build a fully operational network of GIS stations to enable a variety of users to share in a marine environment information system. In other words the electronic mail network system will be linked to distributed GIS's to allow for GIS functionality over the network.

3.4.1.2 Some Other On-Line Databases

Most of the information in this section is taken (with permission) from Bostock (1994). This, together with Butler and LeBlanc (1990), is one of the few hard-copy sources which gives specific references to on-line database sources on aquatic sciences. Bostock is useful in that it provides a clear and simple overview on networking generally, and in the "Guide to Resources" chapter, the author not only outlines factual databases but also gives details on electronic bulletin boards, mail lists and newsgroups, bibliographic databases, library catalogues and various other document sources. The Appendices contain a comprehensive listing of database services, networking groups and organisations plus numerous references on networking. We have selected a range of factual on-line databases which could provide useful data for input to a marine fisheries GIS.

(i) CHRONOS FISH. This is a database of fisheries statistics providing annual catch data for more than 1000 varieties of fish per statistical zone for every country in the world, monthly data on landings at European Community ports, statistics on the European fishery fleet, summary data on foreign trade and on supply balance for fish products. Information starts in 1988 and is available in French, German and English. Access is via the networking system WEFA CEIS.

(ii) NEEDS-AG. This is a time series database, commencing in 1960, of Japanese agricultural, forestry and fishery statistics. It is available in Japanese and English via NEEDS-NET.

(iii) MEDIFAUNE. This is a textual and numeric database on 6000 Mediterranean marine animals, their distribution, ecology, life history, biology, etc. It is produced by the University of Nice and is available through the Centre Interuniversitaire de Calcul de Nice et Toulon. Its records start in 1758 and they include some information on the markets for marine species.

(iv) OCEANIC. This is the University of Delaware Oceanography Service. It contains on-line oceanographic data including the World Oceanic Circulation Experiment (WOCE), research ship schedules and a Who's Who of E-Mail addresses in ocean science. Access is via Telnet.

(v) USNO. The U.S. Naval Observatory Automated Data Service provides a database on navigational information, satellite positioning, astronomical data and software utilitics. Access is again via Telnet.

(vi) ODES. The Ocean Data Evaluation System has been developed by the US Environmental Protection Agency. It contains over two million records and data from a range of EPA programmes and the system resides on a mainframe at the EPA National Computer Center in North Carolina.

3.4.2 Remotely Sensed Data Sources

Satellite derived RS data is usually available at a variety of pre-processed levels. According to Stuttard (1992) this causes problems for GIS users in that the majority of data supplied is typically "level 1" data which consists of raw reflectance values which have been geo-referenced. For GIS use it is desirable that processing to "level 4" (or beyond) has been undertaken, i.e. the image has been corrected for distortions (see Section 4.6) and various other pre-processing work has been undertaken. Even then many GIS users will require details on actual land use (or the meaning of the reflectance variations), as shown by the pixel values, and this is not usually available. However, with this need to both make RS imagery more user friendly and to ensure that costs can better be covered via adding value to the products, some of the major RS data suppliers are now supplying imagery to suit customer demands, e.g. Satellitbild, SPOT Image and the National Remote Sensing Centre (NRSC) in the UK can supply geometric and radiometrically adjusted image data on various storage media, and most major suppliers can offer products which have been pre-processed to various customer defined levels and which are centered on customer chosen spatial centroids. One example is the NRSC and Ordnance Survey's seamless national RS dataset, which is offered in various formats and scales, and which has been ortho-corrected such that it can easily be integrated into many GIS's, perhaps to form a background to vector displays. A promising future growth area for remote sensing is in the supply of backdrop imagery, either for use in specialist GIS generated maps or for topographic mapping, and many new companies are now marketing RS image processing software which is usable by non RS specialists.

A major problem with acquiring satellite RS data is knowing exactly what is available from the huge quantity of Earth observation data which is now being received, and which has been collected in the past. To help with this problem new image data searching facilities are about to come on line. For instance, the European Space Agency (ESA), in conjunction with the EC's Centre for Earth Observation (CEO), are developing a user interface terminal to provide a single point of access to multiple inventories of satellite imagery. This follows the development of a robust cataloguing model, under the auspices of the Committee on Earth Observing Satellites, which lays down a rigorous, structured approach to data entry into catalogues. The catalogues will be able to be queried so as to answer such questions as - "List all the cloud free images available for SPOT-2 data of the Red Sea taken during 1992". This system should be fully functional by 1998. A similar system is operating in the USA. Here the various offices of the National Cartographic Information Center (NCIC) can help individuals locate images via computer database search facilities. Following this same conceptual basis, plans have been put forward for the establishing of a "Marine Remote Sensing Information System" (MARSIS) (Barale, 1991).

Imagery may be obtained from a range of local, national and international sources, some who specialise in one satellite system whilst others may provide for all systems plus a range of other

connected services. Figure 3.8 gives an example of the type of information which would need to be supplied in order to obtain RS imagery, with this particular form being applicable to registered ERS-1 users. Some examples include:

(a) EOSAT - this is the USA distributor of Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data, and a world distributer of IRS 1A and 1B data.
(b) Eurimage - they are the main European distributor for Landsat, ERS and other satellite data and they operate through 35 local distributors in Europe, North Africa and the Middle East.
(c) Remote Sensing Technology Centre (RESTEC) in Tokyo distributes MOS-1 data in Asia.
(d) SPOT Image in France prepare and distribute a wide range of SPOT imagery through a worldwide chain of distributors.
(e) The European Space Agency (ESA) has a GENIUS programme to process, archive and distribute imagery, mainly using computer networking facilities. They handle data for several satellite systems. ESA have a chain of European distributors.
(f) The NPA Group - they offer all imagery plus image processing equipment and expertise and they are specialists in Russian RS data.
(g) When the one metre resolution imagery becomes available in 1996 it will be marketed by a new US company called Eyeglass.
(h) The National Remote Sensing Centre Ltd (NRSC) are the main UK distributor for all RS products.
(i) The National Aerospace Laboratory (NLR) are the main Dutch RS distributors.
(j) Worldmap is a new consortium formed between a western company (Jebco) and two Russian remote sensing agencies, with the aim of processing and distributing both new imagery and that from the Russian archives.
(k) In the USA, the U.S. Geological Survey (USGS) produces and distributes RS data sets on a world wide coverage from both Landsat and AVHRR sources, and prices for scenes which are more than two years old reflect only the cost of reproduction.

Most developed countries now have at least one major distributing company plus often a number of private RS distributing points. Many of the suppliers also have contracts with various Russian agencies to secure their data. Much of this is in the form of high resolution (down to 2 metres) black and white photographic images though a vast amount of other digital data is also available. There are also emerging specialist companies who will provide satellite derived information which is specifically oriented towards the fisheries industry, e.g. hardcopy data on sea surface temperatures and ocean fronts. Since this information is in mapped format, it could usefully form the basis from which scanned maps could be derived (see section 4.5.2).

Typical costs for satellite imagery vary according the source, scene size, the degree of pre-processing, etc. Table 3.4 gives an indication of prices for a small sample of the total imagery product range. However, since there are now so many companies supplying data, there is plenty of pricing competition and it is often possible to buy older imagery, or bulk purchases of several images, at much reduced prices. Some satellite data is available in near real time, e.g. for a premium price, processing and delivery of ERS-1 SAR imagery can be obtained in 30 minutes,

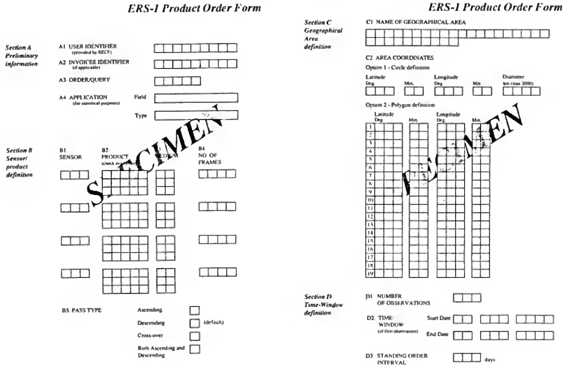


Figure 3.8 Example of a Satellite Imagery Product Order Form for ERS-1 Output

and SPOT charges an extra US$2000 per image for archive scenes provided within 24 hours. Two useful sources of information which specifically relate to RS and the marine environment are Commission of the European Communities (1991) and UNESCO (1992).

Table 3.4 Examples of 1994 Prices for Some Remote Sensing Digital and Photographic Products

*	ERS-1 Synthetic Aperture Radar (SAR), Full image, Digital products	US$2350
*	SPOT Panchromatic, Full scene (60 x 60 km), Minimal correction, 10m resolution, Digital (CCT or CD-ROM)	US$3200
*	SPOT Panchromatic, Full scene (60 x 60 km), Minimal correction, 10m resolution, Photographic print at 1:100 000 scale	US$175
*	SPOT Multispectral, Full scene (60 x 60 km), Minimal correction, 10m resolution, Digital (CCT or CD-ROM)	US$2500
*	Landsat Thematic Mapper (TM), Full scene (185 x 185 km) 7 bands, 30m resolution, Minimal correction, Digital (CCT)	US$4600
*	Landsat Thematic Mapper (TM), Quarter scene (90 x 90km), 7 bands, 30m resolution, Minimal correction, Digital (CCT)	US$2350
*	Landsat Thematic Mapper (TM), Black and white photo, Full scene at 1:250 000 scale, 1st print	US$450
*	Russian Panchromatic, System KFA-3000, Full scene (21 x 21 km), 2m resolution, Digital on 9 track tape	US$4800
*	Russian Panchromatic, System KFA-1000, Full scene (80 x 80 km), 5m resolution, Digital on 9 track tape	US$3600
*	Russian System MK-4, Four spectral bands, Full scene (170 x 170 km), Minimal processing, 8 m resolution Digital on 9 track tape	US$5400

3.4.3 Other Digital Data Sources

In this section we are considering the acquisition of a miscellany of digital data which may be available, usually on floppy disk or in CD-ROM format. Since the range of data could be virtually infinite, we can only list a sample of the types of product which are on offer. Although illustrations are drawn mainly from Europe and North America, in many cases there may be similar source institutions in other areas or the institutions mentioned have data for a wide range of marine locations. It is likely that many of the sources mentioned will soon release their data via computer networking systems. Table 3.5 shows typical digital mapping data available (plus prices) for a range of European information. Some of the GIS Trade Directories provide lists of digital data providers (see Section 8.3), and there are a number of general database

directories, e.g. ACCIS (1990) and Nolan (1995). Before purchasing any of the digital data described in this section, the user should check its format, structure, accuracy, geographic area covered, date and its price.

Table 3.5 Availability and Price (1995) of Selected Digital Data for Europe

Digitised Outlines	Price (US$)
Motorways	1 200
Primary and Main Roads	2 300
Secondary Roads	1 500
Motorways, Primary and Secondary Roads	4 500
Railways	750
Rivers, Canals, Coastlines and Lakes	3 000
Country Borders	1 000
Coastline	1 500
Contours at 300, 600, 1200, 1800, 2400, 3000, 3600 metres	1 500
Europe at 1:3,000,000	3 750
Europe at 1:2,000,000	6 000
Europe at 1:1,000,000	12 000

(a) The UK Ordnance Survey is now making available, initially on a trial basis, a number of coastal zone maps in digital format (see section 9.6).

(b) The UK Department of the Environment produces a "North Sea Research Database" which is an integrated, PC-based system providing information on individuals, organisations and projects concerned with the North Sea.

(c) The British Oceanographic Data Centre (BODC) maintains a national oceanographic database which provides a broad range of data to research scientists, industry and to local and central government. It has also produced a UK Digital Marine Atlas (UKDMAP) (see section 9.3).

(d) As mentioned in section 3.2, digital hydrological charts are now becoming available. As well as obtaining these via networking, Wardle (1992) reports that these will be available on disk either as integrated parts of complete navigation software packages, or as separate digital maps for specific areas. Kingfisher Charts (see section 3.2.1) are now producing, in conjunction with the French marine research organisation IFREMER, a database called the European Seabed Information Service (ESIS). This will map all navigation and sea bed hazards in EC waters (Knox and Lalwani, 1994).

(e) The US Defense Mapping Agency has produced a digital data file known as the World Vector Shoreline (WVS). It is at a nominal scale of 1:250 000, contains shorelines,

international boundaries and country names and is in a format suitable for integration into most GIS packages via magnetic tape or CD-ROM (Soluri and Woodson, 1990). Various "spin-offs" or value added products have been produced from this work, e.g. MundoCart from Chadwyck Healey.

(f) A similar product to the above is the Digital Chart of the World. This provides topological vector data at a base scale of 1:1 000 000 for the whole world, which makes it much more amenable to GIS uses (Danko, 1992). It comes on 4 CD's and contains about 1 700 Mb of data. It can be obtained from Chadwick Healey Ltd for about US$300.

(g) The Public Works Department in the Netherlands initiated a North Sea "Marine Information Service" (MARIS) in 1985. This is a complete service which not only provides digital database information on disk (and on-line) but also carries out research, consultancy and gives guidance, etc. (van Eden, 1992).

(h) The Eurostat GISCO project. Eurostat is a branch of the European Commission and is based in Luxembourg. The role of GISCO is to identify EC spatial data requirements and subsequently to acquire and maintain this data. A range of large databases are now available, many of which are marine related (Cubitt, 1992).

(i) The GENIE (Global Environmental Network for Information Exchange) project has been established at Loughborough University in the UK, to provide a global environmental change data network.

(j) The U.S. National Oceanic Data Center (NODC) can provide the following data sets on CD-ROM, magnetic tapes, diskettes or over Internet:

- GEOSAT global wind/wave data, collected by satellite.
- NODC taxonomic code data, i.e. a system of numeric codes used to represent the Linnean scientific names for organisms.
- NOAA marine environmental buoy data, i.e. 14 CD-ROM's hold worldwide data collected from buoys on air temperature and pressure, wind speed and direction, wind gusting and sea surface temperature plus some data on waves.
- NODC oceanographic station profile time series, i.e. these represent repetitive samples of parameters such as salinity, temperature, density, nutrients, etc, along ocean sections or at fixed stations for long time periods.
- GEOSAT altimeter data which contains various geophysical parameters.

(k) Barale (1991) reports the development of the Marine Remote Sensing Information System (MARSIS). This system is designed to make a far higher proportion of the RS marine data gathered available to potential users by delivering value-added data sets, both

according to standard statistical procedures and to specific user requests. MARSIS data would originate from a number of regional centres which covered complete sea basins, e.g. the entire Mediterranean region.

(l) The International Council for the Exploration of the Seas (ICES) has a large oceanographic digital data bank which is continually being updated. This covers a wide variety of parameters. Details regarding access to this data, the nature of the data and its format can be obtained from the Working Group on Marine Data Management at ICES headquarters at Palaegade 2-4, DK 1261, Copenhagen K, Denmark.

(m) Floen et al (1993) reports the establishment of an integrated database for marine research at the Institute of Marine Research in Bergen, Norway. This is a centralised database containing all data gathered by the Institute. It mostly covers the Scandinavian areas and the data comes under the broad headings of "Marine Resources", "Marine Environment" and "Aquaculture".

(n) The British Marine Fishes Database (BMFD) has been developed by the Marine Biological Association, Citadel Hill, Plymouth, UK, and it covers aspects relating to the biology and ecology of all marine fishes found in waters around the British Isles.

(o) Froese (1993) reports on the current status of "FishBase", which is a global database on over 8000 fish species, This has been developed by a consortium of international organisations including the EC, FAO and the International Center for Living Aquatic Resources Management (ICLARM).

(p) For some parts of the world's oceanic areas, there are now databases of digital acoustic sounding data. Hittelman et al (1989), McLain et al (1991) and Danko, 1992) can provide further information on these.

(q) The National Ocean Service (NOS) in the USA collects and distributes bathymetric data for all of the USA and territories, plus other islands in the Pacific and Atlantic.

(r) The National Wetland Inventory (NWI) of the U.S. Fish and Wildlife Service provides information on wetland location and type, in digital format at a scale of 1:24 000 for most of coterminous USA. Wetlands are classified according to a Cowardin wetland classification scheme (Figure 3.9).

(s) The FAO Fisheries Department has published a database which forms a global inventory of commercially important fish species (Coppola et al, 1994). The database is called SPECIESDAB, and it was created to offer quick and easy access to fisheries and biological information on over 3000 marine species.

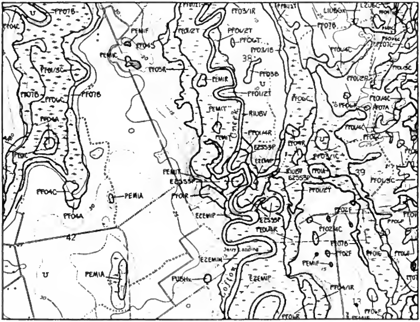


Figure 3.9 Portion of the National Wetland Inventory Map in Florida, USA

(t) UNESCO, in conjunction with the International Oceanic Commission (IOC), produces a "MEDI Catalogue" which is a catalogue of digital data holdings relating to marine environmental data (UNESCO, 1993).

CHAPTER 4 - PREPARING DATA FOR INPUT TO A MARINE FISHERIES RESOURCE GIS

4.1 Introduction

The primary and secondary data which has been collected, and which forms the essential input to the marine fisheries GIS, will be in numerous formats. Though some of it may already be suitable for immediate input to the GIS, the majority of it will require conversion to a suitable digital form. Once converted this data can be stored ready for input, either on computer compatible tapes (CCT's), floppy disks or CD-ROM's. This chapter is concerned with the various methods of undertaking this data preparation or transformation. It is important to note that the discussion will be in general terms only, i.e. particular GIS software packages may require that the digital data be encoded in a specific format or using a particular database, and the GIS user will need to check the requirements of individual software systems. It is also important to point out that much of the content of this chapter, and of Chapters 5 and 6, may not be particularly oriented towards marine fisheries per se.

Three concepts which are of fundamental importance to data preparation for a GIS, and over which there has been some confusion, are those of data models, data structuring and databases. Various sources tend to use the terms "data models" and "data structuring" interchangeably. We will briefly discuss data models in this introduction and our interpretation of data structuring will be considered in Section 4.2. A background to databases for GIS will be given in both Sections 4.2 and 4.3, but the management of databases will be left until Chapter 6, i.e. since this usually forms part of the GIS operating process. A diagram which illustrates the necessary steps from the real world to the output of maps from the GIS, is shown as Figure 4.1. At each stage it is necessary for the data models to be structured in an organised way.

"Data models" (or data modelling) refers to the way in which spatial information is organised from the conceptual viewpoint. Thus, when we are working on a GIS task, what we are essentially doing is manipulating models of the real world. Because we are concerned with geography, or with analysing space, then the real world has usually been changed to the model we know of as a map. As in the real world, the map will consist of a large number of different objects, e.g. roads, houses, forests, coastlines, each of which are depicted in their own way using some form of symbolism, and each of which we should be able to recognise (perhaps with the help of a key). Since the map is a simplification of the real world, it is important to recall that whatever is put onto the map is a transformation of the real world situation. Thus, in order to generalise for mapping purposes, aggregations may have been made of any type of spatial phenomena, and in many cases classifications will also have been made, e.g. complex classes of coastal zone land use may be combined under a single definition. A fisheries example might be that a consideration is necessary about what categories different fishing vessels are going to be subdivided into, and it may be necessary to even consider what counts as a fishing boat. We point these facts out since it is important to show that any mapping and GIS exercise, starts off

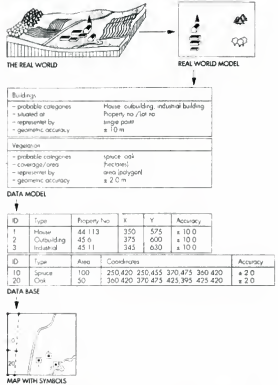


Figure 4.1 Schematic Diagram Showing How the Real World is Transformed to Obtain GIS Output (from Bernhardsen, 1992)

from a position of using very much simplified (modelled) information. It will have been essentially the cartographers task to have transformed the real world into a mapped world with the minimum of information loss and distortion.

As a further introductory note, we need to emphasize strongly from the beginning the importance of data quality. The data capture of both primary and secondary information can be a costly and time consuming part of setting up a GIS. Having completed this capturing task, the data itself may well have a life which far exceeds that of the hard or software being used. In view of this input of effort, it is vital that the data secured has a high degree of utility, and this will only be achieved if the data is of the highest quality. There are many ways to ensure data accuracy and

quality, and we recommend a study of Goodchild and Gopal (1989) or Thapa and Bossler (1992) for overviews. It is also important to note that attempts are being made by GIS communities in many countries to define and adopt certain standards for the collection of, and transference of, digital data. Standards have already been drawn up in many countries and these will have an enormous impact on helping not only to ensure data quality, but also in providing cost savings in not having to embark upon various data conversions which would be necessary if the data was transferred in any variety of formats. Thus, in the establishing of any databases, it is essential that consideration be given as to whether or not there are certain criteria which should be followed if it is intended that the data should either be available for transferring to other databases or GIS's, or if it to be utilisable by specific GIS's. Further details on standards in GIS data can be found in Sowton (1992) and Cassettari (1993) and, recognising the importance of this issue, the whole edition of the journal "Cartography and Geographic Information Systems" for July, 1994 (Vol.21, No.3) was devoted to the subject of standards.

4.2 The Structure of Spatial Data

Data structuring is the actual method adopted for organising and storing data in a database. Essentially this means that, to be of value to a GIS, data must be processed and arranged in a database in such a way as to be meaningful and consistent to a wide range of users both in the present and in the future. For the GIS to function it requires the input, in digital form, of two sorts of information: (i) where an object is located on the map, and (ii) what an object on the map represents. These two sets of information make up the two main kinds of databases which necessarily must be built up as part of a GIS - they are commonly referred to as graphical (containing geometric or spatial information) and non-graphical (containing attribute or feature code) databases. Although in practice some GIS's store the graphical and the attribute data together in the same database, in this section we shall only be considering the structuring of the spatial data; the structuring of non-spatial data is examined in Section 4.3. Further Information on the importance of data structuring is given in Burrough (1986), Star and Estes (1990), Martin (1991), Bernhardsen (1992) and other basic GIS texts. Rackham and Gower (1993) discuss an important model which describes all the characteristics (or specifications) which data should adhere to if it is going to be of optimum use in a GIS, i.e. in terms of data content, classification methods, data structure, data capture and update, data presentation and data quality. A data inventory method has recently been proposed for the development of fisheries GIS applications, i.e. within a West African marine fisheries GIS being developed by the FAO (Taconet and Bensch, 1995).

From our brief discussion above on modelling, it is clear that the GIS must have some way of recognising where any data is referring to. An easy way to conceive of how this is accomplished is to first understand that in essence all geographic or spatial entities, i.e. the symbolism that has been created on the map, may be subdivided into only three categories:

i) Points. These can be imagined as dots on a map. The dot may represent anything which is located in one place, e.g. a port, a dock, a hatchery, etc. It will immediately be noted that, whether or not a feature can be represented as a point,

depends on the scale of the map on which it may be shown. Thus, on a small scale map, e.g. 1:1 000 000, a town will be shown as a point but the same town would not be a point on a 1:10 000 map.

ii) Lines. These may represent any linear feature such as a road, railway, stream or a fence. At most mapping scales these features will retain their linear form, though, as with points, the degree of detail and generalisation will vary with scale. In GIS terminology, the point at which two lines (also called segments, arcs, chains or links) intersect is called a node.

iii) Areas. These represent 2-D unitary blocks of surface space. In GIS or spatial analysis jargon they are referred to as polygons. They may be EEZ's, lagoons, mangroves, lakes, etc. When shown on maps at a very small scale these features may also eventually become points.

Obviously the mapped objects themselves will also have another dimension, that of height, and indeed data on this is frequently compiled and stored. But for GIS and mapping purposes, physical output from the system can only be in two dimensions, although it is possible to display 3-D looking images on the computer screen.

A GIS functions by having an internal coding system which utilizes various ways of allocating location to these three types of spatial entity. Thus points may be readily located by using a co-ordinate referencing system; linear features may be represented by breaking their "stretches" down into straight sections and then allocating co-ordinates to the nodes at the ends of each stretch, and areas may utilise co-ordinates to locate the boundaries (corners) of enclosed polygons. When geo-referencing, it is important to the GIS software that a unique identifier is assigned to all data, i.e. an identifier which is able to be recognised by its pre-programmed label or co-ordinate, and one which is able to be linked to the data in an attribute database. We can now give some examples of geo-references which are acceptable and commonly used.

a) Topographic grid references. All official Ordnance Survey (topographic) maps have a system of grid referencing. This is often based on the Universal Transverse Mercator (UTM) system, but other map projection systems may also be used. So for any point feature, or intersections of linear features, or the corners of areas, etc., a co-ordinate can be given. The accuracy of this point reference will be a function of both the mapping scale and the task being carried out. A commonly used variation of grid referencing is the use of latitude and longitude co-ordinates.

b) Post-codes or ZIP codes. These identifiers usually refer to an area as delimited for postal servicing (Figure 4.2). The hierarchical nature of many post codes gives the ability of analysing spatial data at differing resolutions.

c) Street names. These are easily allocated and identifiable but data can only be aggregated to street level which may be sometimes be inconvenient for mapping purposes. Obviously other linear features may also have names such as motorway numbers or river names.

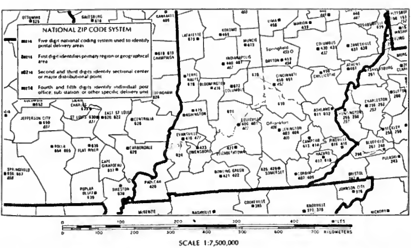


Figure 4.2 Example of the National Zip Code System Used in the USA (after Robinson et al, 1995)

d) Other named aerial units. Aerial units names may progressively vary in size from villages, towns, cities, states and countries or they can obviously refer to other non-urban features such as lakes, forests, seas, etc. In many cases information may relate to areas which have been created (and labelled) for special purposes such as conservation areas, natural vegetation zones, sales force areas, divisions of the sea, fishery statistics areas, etc.

e) Census division names. Many countries have divided their area, for the purposes of gathering census and other social or economic data, into a hierarchy of recognised ward or district areas.

Having established that there are the three types of spatial data (points, lines and polygons), and that these can be georeferenced in various ways, it is now important to show how these features can best be structured in ways that the GIS software will understand.

The most successful data structures are those that offer the greatest flexibility in the various manipulations and analyses which will be described in Chapter 6. There are two basic data organisational structures (also called modes, models or formats) which GIS programmes use for spatial data: (i) the vector mode and (ii) the raster mode, though Cassettari (1993) gives information on other ways of structuring data. A simple comparison between the vector model (A) and raster model (B) is shown in Figures 4.3.

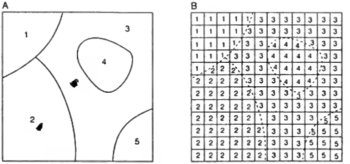


Figure 4.3 Comparison Between the Vector Model (A) and the Raster Data Model (B)

4.2.1 The Vector Data Structure

In the vector data structure points, lines and polygons are all recorded in terms of their geographic x and y co-ordinates. The vector data structure is thus concerned with boundaries. In practical terms, this means that the person operating the GIS will, for any particular GIS task, have instructed the software as to the possible extremes of the map, i.e. a geo-reference for the top right hand corner and bottom left hand corner. The detail of the geo-reference in terms of its measurement precision, e.g. grid references to four decimal places, will determine the accuracy of the finished map. When the particular mapping details (co-ordinates) are then entered into the graphical database, they must have geo-references which are within the extremes of the map as programmed. Obviously, for the drawing of any particular map, many thousands of co-ordinates may be necessary. Together with the co-ordinate data, instructions are entered on which points along a line are connected or unconnected. These instructions will trigger "pen up" or "pen down" functions during map drawing. To obtain perfect curves or parabolas which, if drawn in detail, could involve the entry of hundreds of co-ordinates, it is possible to simply enter any curve equation function which the GIS recognises or the use of spline functions can be made (see Burrough, 1986 or Laurini and Thompson, 1992, for details).

The actual vector graphical database which is built up to store the locational information on the mapped entities (points, lines or polygons) will be in a coded digital format. The allocation of unique identifiers to mapped objects will often be based on a hierarchical coding system as shown in Figure 4.4. Here we can see that there are major object groups and within each of these there may be various sub-category levels. The database itself then might consist of a string of numerals, one portion of which might read:

-541004831864689434279598052-5

This would be intelligible to the GIS software as:

Numeral	-5	= Start of the drawing sequence
	4100	= unique identifier
	48	= line thickness to be drawn
	31864	= first Easting co-ordinate
	68943	= first Northing co-ordinate
	42795	= last Easting co-ordinate
	98052	= last Northing co-ordinate
	-5	= end of line sequence - start of next sequence

There would usually be a separate string of numerals for each object type on the map and all object types would need to be registered to a similar geo-referencing system. This particular type of numeric string could clearly be used to produce a mapped image which was composed of lines, points and polygon boundaries. It is normal for all the co-ordinates in one database to refer to only one class of objects, e.g. coastal boundaries, or roads, or rivers, etc. Each of the databases can then be used to produce a single mapped "layer" and several "layers" may be superimposed to produce a single vector map (Figure 4.5).

Numerical code series	Object group
1 000	Survey control stations
2 000	Terrain formation
3 000	Hydrography
4 000	Boundaries
5 000	Built-up areas
6 000	Buildings and facilities
7 000	Communications
8 000	Technical facilities

Numerical code	Object type
4 001	National border
4 002	County boundary
4 003	Township boundary
4 011	Property boundary
4 022	National park border
	etc.

Figure 4.4 Numerical Coding Allocated to Vector Graphical Data In Order to Identify Different Object Categories

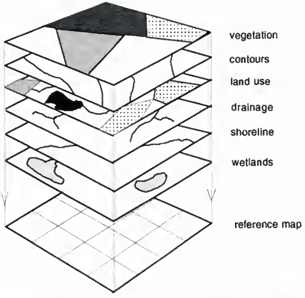


Figure 4.5 A Model Showing the Layers Used to Construct a Basic Vector Coastal Zone Map

The vector data structure can be subdivided into two models. When vector data is in a crude form it might simply consist of strings of lines which follow the co-ordinates which have been entered into the database. The lines might be unconnected, they might cross one another, common boundaries might have been registered twice and there is generally no logical structure to the data. This is called "spaghetti" data. Although it can be efficiently presented on the screen or printed out, i.e. because its co-ordinates are recorded in an attribute table, it may be of little use to a GIS because the relationship between points, lines and polygons is unknown. For geographical search or analysis, the second vector model must be used, i.e. the topological model (or "intelligent vectors"). A vector topological data structure is shown in Figure 4.6. This structure is concerned with establishing the location of objects with respect to each other, by defining connectivity, adjacency and containment. In topology, end points and the intersection of lines are recorded as nodes, the lines are links between the nodes, and the enclosed areas defined by a chain of links are recorded as polygons. The topological structure allows spatial relationships to be explicitly defined in an attribute database as per the topological encoding shown in Figure 4.6. Once topology has been established for any mapped layer it is then easier to update the data, and it means that information storage requirements are less since data on

shared lines or nodes does not need to be entered twice. It also means that many true GIS manipulation or analytical functions can then be performed.

4.2.2 The Raster Data Structure

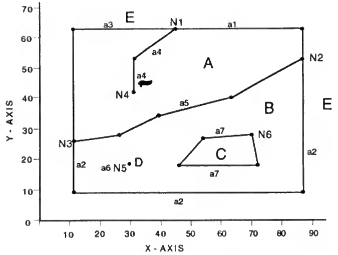
This data structure is concerned not with boundaries but with the space between boundaries, i.e. all areas of the map must be allocated an attribute or a value for this attribute. Boundaries are only implied as lying where value changes occur. The basic raster structure, covering the same "mapped" area as shown in Figure 4.6, is shown in Figure 4.7. It is sometimes called the grid model because data is stored in a matrix of cells (which themselves may be called pixels). These cells are usually square but they may be rectangular, triangular or hexagonal, or indeed any regular shape which is capable of tessellation. The raster data structure is favoured for mapping where the main objects dealt with are spatially extensive areal units, i.e. rather than linear or point units.

It is clear that the resolution of objects depicted using this data structure will depend entirely upon the size of cells used. A comparison of Figures 4.6 and 4.7 make it clear that use of the raster format may produce maps which have a very crude resolution, but which require little computer storage space. Also, since each cell can only record one value per map theme, then it is important to remember that this value will either be the "average" or the modal value of all variations within a cell, or it may be the value obtaining at the central point of the cell. The importance of selecting an appropriate cell size in which to divide up any mapped area has been outlined by Valenzuela and Baumgardner (1990), and this size will be a reflection of several factors such as the accuracy of the original data, the purposes of the mapping exercise, and the availability of computer disk storage space.

Geo-referencing, and hence location, in the raster structure is by means of simple alphanumeric codings for vertical and horizontal cell columns and rows. Each code will usually correspond to an object on the map, although it can also correspond to a different colour shading or reflectance value, i.e. as per the pixel dot shadings which make up a newspaper picture or the reflectance values which are obtained via a satellite RS image. Like the vector model, raster maps are also built up in thematic layers. However, in the raster structure it may be necessary to have far more layers - this is because there is only one value per pixel and therefore this value cannot contribute to a detailed attribute table.

Using the raster structure it is essential to record some value for every pixel (cell). This can lead to very large data storage requirements, especially if a fine pixel resolution is used. For instance, a single Landsat Thematic Mapper image contains about 35 million pixel values. In order to overcome this problem, two main data compression techniques have been devised:

(a) Run length encoding. Figure 4.7 showed how run length encoding has been applied to the map shown. Since many adjacent cells share the same value, for



TOPOLOGICAL ENCODING

POLYGON TOPOLOGY

Polygon	Arcs
A	a1, a5, a3
B	a2, a5, 0, a6, 0, a7
C	a7
D	a6
E	area outside map

ARC TOPOLOGY

Arc	Start Node	End Node	Left Polygon	Right Polygon
a1	N1	N2	E	A
a2	N2	N3	E	B
a3	N3	N1	E	A
a4	N4	N1	A	A
a5	N3	N2	A	B
a6	N5	N5	B	B
a7	N6	N6	B	C

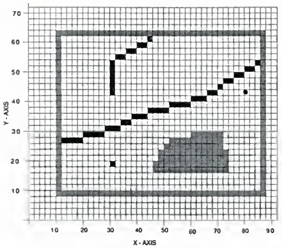
NODE TOPOLOGY

Node	Arcs
N1	a1, a3, a4
N2	a1, a2, a5
N3	a2, a3, a5
N4	a4
N5	a6
N6	a7

ARC COORDINATE DATA

Arc	Start X, Y	Intermediate X, Y	End X, Y
a1	45, 63	87, 63	87, 53
a2	87, 53	87, 9; 11, 9	11, 26
a3	11, 26	11, 63	45, 63
a4	45, 63	31, 53	31, 42
a5	11, 26	27, 28; 40, 35; 63, 40	87, 53
a6	30, 18		30, 18
a7	70, 28	73, 17; 46, 17; 54, 27	70, 28

Figure 4.6 A Simple Vector Map Having a Point, Lines and a Polygon With Their Associated Topological Encoding



RASTER RUN LENGTH CODE STRUCTURE

Row	Run length encoding
86	0, 90, 0
64	0, 90, 0
62	0, 8, 0; 10, 88, 1; 88, 90, 0
60	0, 8, 0; 10, 1; 12, 42, 0; 44, 2; 46, 84, 0; 86, 1; 88, 90, 0
58	0, 8, 0; 10, 1; 12, 38, 0; 40, 42, 2; 44, 84, 0; 86, 1; 88, 90, 0
56	0, 8, 0; 10, 1; 12, 34, 0; 38, 38, 2; 40, 84, 0; 86, 1; 88, 90, 0
54	0, 8, 0; 10, 1; 12, 30, 0; 32, 34, 2; 36, 84, 0; 88, 1; 88, 90, 0
52	0, 8, 0, 10, 1; 12, 28, 0; 30, 2; 32, 82, 0; 84, 2; 86, 1; 88, 90, 0
50	0, 8, 0; 10, 1; 12, 28, 0; 30, 2; 32, 78, 0; 80, 82, 2; 84, 0; 86, 1; 88, 90, 0
48	0, 8, 0; 10, 1; 12, 28, 0; 30, 2; 32, 74, 0; 78, 78, 2; 80, 84, 0; 86, 1; 88, 90, 0
46	0, 8, 0; 10, 1; 12, 28, 0; 30, 2; 32, 70, 0; 72, 74, 2; 78, 84, 0; 86, 1; 88, 90, 0
44	0, 8, 0; 10, 1; 12, 28, 0; 30, 2; 32, 88, 0; 70, 2; 72, 84, 0; 88, 1; 88, 90, 0
42	0, 8, 0; 10, 1; 12, 28, 0; 30, 2; 32, 64, 0; 66, 88, 2; 70, 84, 0; 86, 1; 88, 90, 0
40	0, 8, 0; 10, 1; 12, 58, 0; 60, 84, 2; 66, 84, 0; 86, 1; 88, 90, 0
38	0, 8, 0; 10, 1; 12, 50, 0; 52, 58, 2; 60, 84, 0; 86, 1; 88, 90, 0
36	0, 8, 0; 10, 1; 12, 42, 0; 44, 50, 2; 52, 84, 0; 88, 1; 88, 90, 0
34	0, 8, 0; 10, 1; 12, 36, 0, 38, 42, 2; 44, 84, 0; 86, 1; 88, 90, 0
32	0, 8, 0; 10, 1; 12, 32, 0; 34, 38, 2; 38, 84, 0; 86, 1; 88, 90, 0
30	0, 8, 0; 10, 1, 12, 26, 0; 28, 32, 2; 34, 84, 0; 86, 1; 88, 90, 0
28	0, 8, 0; 10, 1; 12, 18, 0; 20, 28, 2; 28, 58, 0; 60, 70, 1; 72, 84, 0, 86, 1; 88, 90, 0
26	0, 8, 0; 10, 1, 12, 18, 2; 20, 50, 0; 52, 70, 1; 72, 84, 0; 88, 1; 88, 90, 0
24	0, 8, 0; 10, 1; 12, 48, 0; 50, 70, 1; 72, 84, 0; 86, 1; 88, 90, 0
22	0, 8, 0; 10, 1, 12, 48, 0; 48, 72, 1; 74, 84, 0; 86, 1; 88, 90, 0
20	0, 8, 0; 10, 1; 12, 48, 0; 48, 72, 1; 74, 84, 0; 86, 1; 88, 90, 0
18	0, 8, 0; 10, 1, 12, 28, 0; 30, 2; 32, 44, 0; 46, 72, 1; 74, 84, 0; 86, 1; 88, 90, 0
18	0, 8, 0; 10, 1; 12, 44, 0; 48, 72, 1; 74, 84, 0; 86, 1; 88, 90, 0
14	0, 8, 0; 10, .1; 12, 84, 0; 86, 1; 88, 90, 0
12	0, 8, 0, 10, 1; 12, 84, 0; 86, 1; 88, 90, 0
10	0, 8, 0; 10, 1; 12, 84, 0, 86, 1; 88, 90, 0
8	0, 8, 0; 10, 86, 1; 88, 90, 0
8	0, 90, 0
4	0, 90, 0
2	0, 90, 0

Figure 4.7 A Simple Raster Map Plus the Run-Length Encoding Structure Used for Data Storage

each row it is only necessary to specify a cell value and column number where that value begins and ends.

(b) Quadtrees. This technique is based on the successive subdivision of the area under study into smaller and smaller quadrants, i.e. according to whether or not areas of a similar value are wholly in the quadrant or are not. The lowest level of subdivision is a single pixel. Figure 4.8 (b) shows the successive subdivision of

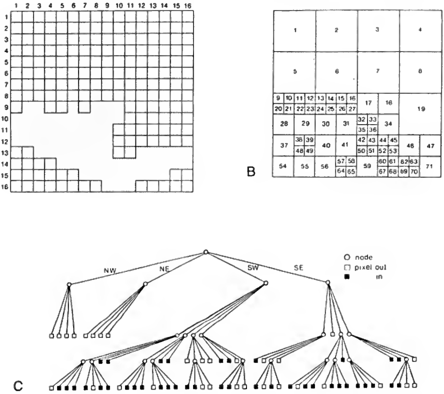


Figure 4.8 Three Stages in the Construction of a Quadtree Data Encoding Structure (from Burrough, 1986)

the stippled area in 4.8 (a). This subdivision is typically shown by a quadtree 4.8 (c). Here it can be seen that there are links and nodes in a directed tree starting from the root node. From each node there are four "edges" representing the four

quadrants of N.W., N.E., S.W. and S.E. Sub-quadrants only emanate from nodes which are shown as being sub-divided in the raster map, i.e. data only has to be saved for cells which have the "value" of the layer being coded. Savings of at least 50% in data volume are possible via the use of quadtrees. Bonham-Carter (1994) provides an interesting comparison between a raster and vector map in terms of the amount of digital storage space required (Figure 4.9). Thus map A is a raster image and, given that 1 byte equals 1 pixel, then it requires 709 042 bytes of storage. The run-length encoded version requires 21 903 bytes, and the quadtree version 19 473 bytes. Map B, the vector version, requires 17 890 bytes.

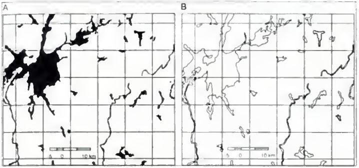


Figure 4.9 Comparison of a Raster Map (A) With a Vector Map (B) (see text for details)

The advantages and disadvantages of each data structure are shown in Table 4.1. Developments in GIS are now at a stage where all sophisticated GIS packages are able to handle both raster and vector processing and it likely that the vast majority of data inputs in the future will be in raster format.

Table 4.1 A Comparison of Raster and Vector Data Models

RASTER MODEL

Advantages

1. It has a simple data structure.
2. Overlay operations are easily and efficiently implemented.
3. Scanning technologies can supply huge quantities of data cheaply.
4. Image processing techniques produce data for integration to GIS in a raster format.

5. Area and polygon analysis is simple.
6. Overlaying and merging are easily performed.
7. The technology is cheap and in the future it will have greater cost advantages.
8. It is well suited to subdividing spatially continuous variables.

Disadvantages

1. The sheer volume of data to be stored and handled can be very high.
2. There can be a serious loss of detail with larger pixel sizes (poor resolution).
3. Final maps can be fairly crude, especially those produced on cheaper GIS software.
4. Linear type analysis is more difficult.
5. Topological relationships are difficult to represent.

VECTOR MODEL

Advantages

1. It has a relatively compact data structure so storage requirements are less.
2. Features can be accurately located.
3. The topology can be completely described with network linkages.
4. Very small features can be shown and all features can be accurately drawn.
5. Data about individual features can easily be retrieved for updating or correction.
6. Linear type analyses are easily performed.

Disadvantages

1. It has a more complex data structure.
2. Overlay operations are difficult to implement.
3. The representation of high spatial variability is inefficient.
4. Manipulation and enhancement of digital images cannot be effectively performed.
5. Data capture can be very slow.
6. Area or polygon analyses are difficult.
7. This is generally a more expensive data structure in terms of data capture and software purchase.

We should conclude this discussion on the structuring of spatial data by mentioning the third dimension. To build up a structured database which contains "altitude", or for marine applications "depth", then triangulated irregular networks (TIN's) are used. These consist of a series of non-overlapping polygons, each defining a flat surface, which completely covers the topographic surface (Figure 4.10). Each vertex of a triangle is encoded with its location and it

has a height associated with it. Given this information, the TIN can be reproduced as a digital elevation model in 2.5-D, the detailed resolution of which depends upon the accuracy of the original TIN. To model volumes in a structured way, a geo-referencing system is needed which encodes in x, y and z axes. A way of doing this is to extend the raster concept of using an array of cellular pixels so as to model the added dimension, i.e. a 2-D square becomes a 3-D cube. These cubes have been called voxels (volume elements). Geo-referencing and attributes can be assigned as in the raster data structuring. Gargantini (1989) describes the work which is in place on "octrees", i.e. as quadtrees are a way of compressing pixel data, these are ways of structuring data which is in voxels. Clearly, the use of voxels will eventually be essential in much marine fisheries GIS work, but as of the present they have been mostly used in the geological GIS field.

4.3 Building Non-Graphical GIS Databases

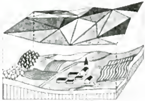
It is important to commence this section by having a clear idea of what a non-graphical database is. A database may be defined as "a comprehensive collection of related data stored in logical files and collectively processed, usually in tabular form." (Bernhardsen, 1992, p4). From the GIS perspective there are two types of non-graphical databases:

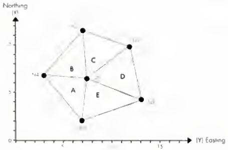
(i) Those databases which may have been compiled as a tabular listing of almost anything.

(ii) Those databases which hold the attribute information relating to specific graphical databases.

We can examine them together since there are no fundamental differences in their structures. A database itself forms the top of a structured hierarchy which consists of fields, records, files and databases. To exemplify this, it can be envisaged that a database could be established on fish landings at a specific port. The database could be organised so that each row (or line) would be a record of landings from each fishing vessel. For these records there would have to be a large number of columns, each of which represented different fields. These fields would each need a title such as "date", "name of vessel", "type of vessel", "fish species landed" (with perhaps a column for each species), etc. At the end of the recording of one day's landings at the port, then a file will have been created. All the files for perhaps a year would constitute a "fish landings database" for the given port. Presumably all the other fishing ports in a country or region would be keeping similarly structured records. Figure 4.11 shows an actual file sheet for recording ichthyoplankton. 15 different "fields" are shown and there is room on the file for 13 records.

The construction of non-graphical databases can be the most expensive, problematic and time consuming aspect of implementing a GIS. Since the data in these databases represents the non-spatial characteristics of objects which could be mapped, such as the name, age, function, height, etc. of the object, then the data will be largely composed of alphanumeric text. Much of it may exist as stored data which has been collected by the various primary collection data methods, e.g. by questionnaires, surveys, etc, or which has been collected from various





Triangle table

Triangle	Adjacent
A	B E
B	A C
C	B, D
D	C E
E	D A

Triangle/Node Table

Triangle	Nodes
A	N3 N4, N6
B	N4 N5, N6
C	N1 N5 N6
D	N1, N2 N6
E	N2 N3, N6

Coordinate tables

Node	Coordinates
N1	X_1 Y_1 Z_1
N2	X_2 Y_2 Z_2
N3	X_3 Y_3 Z_3
N4	X_4 Y_4, Z_4
N5	X_5 Y_5 Z_5
N6	X_6 Y_6 Z_6

Figure 4.10 A Typical Triangulated Irregular Network (TIN) and the Type of Topological Storage Tables Required

secondary sources. Most of the attribute data which is directly tied to the graphical data, will have been entered during the digitising process (see Section 4.4.1). The range of non-graphical data is almost infinite. At a very local scale there might be a database covering local retail fish markets, which was kept and maintained by a local council, whereas, at a different scale, a world database might list all the fisheries statistics for each country, as kept by the FAO.

Page ____ of ____

ICHTHYOPLANKTON SORTING RECORD

Vessel/Cruise: ______________________ Gear/Mesh: ______________________

STATION	HAUL	NET	Sample DATE	No Jars	Sorter	Eggs removed	No Vials	Larvae Removed	No Vials	QUALITY CONTROL			Resort Y/N	Plankton vol
										Eggs	Larv	Checker		

Figure 4.11 An Ichthyoplankton Data Recording Sheet (File)

Non-graphical data can be entered via a keyboard into a conventional database, e.g. an EXCEL spreadsheet or into a commercial database package such as Oracle or dBase, or in some cases the GIS software package will contain its own internal database system. It is important that the input format used throughout a single database is identical, e.g., the same number of fields, widths of fields, the same alphanumeric coding structure within each field, etc. Again there would be an hierarchical attribute coding structure so as to establish levels of object definition, as was shown in Figure 4.4. An alternative method of entering non-graphical (usually tabular) data into any database which is readily accessed by a GIS, is via the use of Document Image Processing (DIP). Here paper based documents are scanned (see section 4.5.2) and the data obtained is stored on some form of electronic storage media (disks or CD-ROM), from whence they can be readily retrieved when desired.

It is of fundamental importance that each record in the attribute database contains a unique identifier, and that this identifier is one that can be recognised by each entry in the graphical database. This will be the only method by which the GIS can link any two sets of data. Frequently, the attribute database will have been compiled with no intentions of it being used in a GIS. In this case it will invariably be essential to add a new "unique identifier" field to the database. The name, grid reference, or perhaps postal code used will need to be in accordance with those existing on any of the graphical data which is to be used. Attribute data may be analysed or queried by conventional methods which do not require reference to location, and attribute databases can be linked to one another by a common unique identifier which is not necessarily the geo-reference. If any useful data is found which is not held in a convenient tabular form, then data conversion packages can often be used to make the data accessible to a GIS.

To conclude this section it might prove useful to mention an actual example of a general fisheries database, i.e. one that is not a specific GIS database. The NAN-SIS software is basically a menu-driven database package which is integrated to various routines, giving it the capacity to perform a range of analyses which are relevant to trawl fisheries surveys (Stromme, 1992). The routines include retrieval, listing, sorting, querying and statistical analyses at different levels. The package has been developed by Norwegian scientists over the past 18 years, as part of the Dr. FRIDTJOF NANSEN research programme. Figure 4.12 illustrates a main section of the database. Note that the data held may be both numeric and alpha-numeric. From the GIS viewpoint it is important that this database contains geo-referenced information giving the location of the trawl start point and the length of haul in nautical miles, i.e. allowing for any data collected to be subsequently mapped. Do Chi (1994) points out that NAN-SIS can be linked to many other specialist packages for the importing or exporting of data. These packages include several major GIS 's including ARC/INFO and IDRISI (see section 5.4.2).

4.4 Metadata

With the potential development of a huge array of both graphical and non-graphical databases, then there will increasingly be a need to keep some kind of record on these. This record will be a means by which background information can be kept on the nature of the data, the sources from where it was derived and the overall quality of the data and data sources. It is all this information which constitutes metadata or meta-information. Table 4.2 shows the types of information which need to be stored in a meta-database (Cassettari, 1993).

Table 4.2 Information Which Needs to be Stored in a Meta Database

* Sources of spatial information.
* Accuracy, quality and currency statements for data sources.
* Explanations of how source data were used to compile the dataset.
* Definitions of attributes and the rules by which they have been coded.
* Rules and procedures adopted for data capture.
* Results from geometric accuracy tests.
* Types of analysis procedures performed on the original data and the constraints and quality of the results.
* Rules for the display and cartographic representation of data.
* Spatial and temporal coverage of any data.
* Methods by which further data can be transferred.

It is likely that some of this data will in fact be stored in an attribute database, e.g. a dataset giving results of a fishery survey would almost certainly give the date when the survey was performed. However, most of the information shown in Table 4.2 is distinctive. The existence of a meta database will greatly help in managing the data side of GIS activities. For instance, by consulting the metadata, then a programme of re-surveys can be instigated or more up-to-date map sources can be sought and obtained. Instructions can also be passed on to data gatherers as to the format for gathering additional information.

Station file: 109 characters, including CRLF
Example:

```
     10        20        30        40        50        60        70        80
12345678901234567890123456789012345678901234567890123456789012345678901234567890123
4567890
WA  1  1OA81 4301235N2040W 171431PT11235 3029862987  16 39 36 39  39 90 200

     90       100       110
12345678901234567890123456789O
301*    55    1732   3464
```

Col.	Explanation
1-2	Project code
3-6	Station number on annual basis
7-10	Station number on project basis. The main key to access data.
11-12	Data entry operators initials.
13-14	Year
15-16	Month
17-18	Day
19-22	Time starting
23-27	Latitude 23:N or S 24-25:deg 26-27: min (Nddmm or Sddmm)
28-33	Longitude 28:E or W 29-31:Deg 32-33 min (Wdddmm or Edddmm)
34	Sectorcode
35	Purpose code 1=for identification 2:trial fishing 3:for swept area
36-38	Gear code BT1=bottom trawl PT1=big pelagic trawl PT2=small pelagic trawl PT4=Small pelagic trawl with floats. OT =Other gear
39-42	Time end of station
43-45	Duration in minutes
46-49	Log start in nm
50-53	Log stop in nm
54-58	Log duration in nm with 2 decimals and point (ll.dd)
59-61	Gear depth at start in metres
62-64	Gear depth at stop in metres
65-68	Bottom depth at start in metres
69-72	Bottom depth at stop in metres
73-75	Course direction 0-360 degrees
76-79	Wire out during trawling in metres
80-82	Speed during trawling in nm x 10
83	Gear condition code
84	Any character, not in use.
85	Validity code
86-91	Sample size in kg with optional 2 decimals.
92-99	Total catch in kg with optional 2 decimals
100-107	Catch per hour in kg with optional 2 decimals
108-109	ASCII codes CR LF

Figure 4.12 The Structure of the Main File in the NANSIS Database

4.5 Capturing Mapped Data

Much of the spatially related data which will have been assembled for GIS input, i.e. the maps, photographs or other images, will not be in digital format. Conversion to this format is performed in one of two major ways: (i) digitising and (ii) scanning. Both of these processes are essentially automatic ways of structuring the mapped data (as we have described in section 4.2) so that it can be "read" by the GIS software. Though the rest of this section describes these two capture methods in some detail, it is important to note that it is increasingly the case that pre-digitised mapped data is able to be purchased either as ready made data sets, or as a customer specified mapping task performed by a specialist digital mapping bureau. The advantages and disadvantages of "in house" versus "agency" data capture are discussed in Clegg (1993).

4.5.1 Digitising

This is the task of converting hardcopy map or aerial photograph outlines into a digital format so that the outlines can be displayed on the screen. A common, and comparatively inexpensive way of doing this makes use of a digitiser. Digitising as a method of outline capture is useful if the purpose is to capture user defined mapping features, or if you wish to add linear features to an existing map. A digitiser consists of a flat, non-conducting surface into which is embedded a cartesian grid of fine wires. These wires are energised and they allow wire intersections to be resolved to a typical accuracy of 0.01 mm. Attached to the digitising table (or smaller digitising tablet) is a tracking pen (or cursor or puck) which features a magnifying glass fitted with cross hairs which itself can be moved around the digitiser recording its position relative to the embedded wire grid (Figure 4.13). A computer (M) is required for viewing digitised work and for recording the digital data captured. Any map or photograph can be fixed to the digitiser surface, and the operator simply selects an outline to follow with the cross hairs on the cursor. As the line is followed one of the buttons on the cursor is continuously clicked so as to record the shape of the line (or the position of a point) as a string of spatial co-ordinates. The cursor may be equipped with up to 16 buttons, which allow for other inputs or operations such as adding identifiers (to link the object being digitised to the attribute data) or for working in stream mode (where the cursor cross hair position is automatically recorded at a pre-set time or distance interval).

Digitisers vary in size from small "tablets" at A4 size, costing about US$500, to larger than A0 size, i.e. 1.0 x 1.5 metres, at US$4 000 plus. Some have background illumination to make line following easier. Most can be linked directly to the computer monitor. This function is useful in that error detection via the zoom facility is easy, and obviously it is useful to know which lines have actually been recorded! The digital information obtained, which is typically vector boundary or network lines (or sometimes point data) with associated attribute names or other information, is either recorded to a floppy disk, or directly on to a hard disk if the digitiser forms part of an integrated GIS.

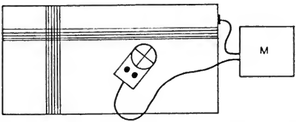


Figure 4.13 Simplified Diagram Showing the Principles of a Digitiser

Digitising is usefully organised so that data is captured in "layers", i.e. with each layer representing a different type of feature, or theme, having its own file name. This allows for easy spatial analysis. Digitising itself can be a time consuming job if done accurately, especially in view of the fact that, to produce a satisfactory final map it is usually necessary to do a great deal of error correction and other editing. An idea of some of the errors which can occur when digitising, and for which editing procedures must be applied, is given in Figure 6.1. Digitising costs can therefore represent a high proportion of a GIS operation. Additional problems are that huge data files can be created from a single map sheet, and manual digitising can only be performed for about four hours daily if accuracy is to be maintained. The degree of detail to which digitising is carried out will reflect the accuracy of the source data, the time and cost efforts which are available and the purpose for which the task is being carried out (Figure 4.14).

Over the last few years there has been a considerable move towards commercial digitising whereby specialist firms provide either digitising services or they provide ready made digital datasets, e.g. the major atlas makers, government mapping agencies and automobile associations are all selling such products. It is also possible to purchase a data maintenance contract whereby a specialist digitising bureau will agree to keep a firm's digital records up to date. A summary of the advantages and disadvantages of digitising as a data capture method are given in Devereux (1992,a).

4.5.2 Scanning

Scanning is also a method for converting hardcopy mapped (or graphics or textual) outlines into a digital form, but unlike digitising, which relies on human judgement to select desired mapped features, scanning captures all of the information on a given sheet very quickly. A typical large topographical map measuring 1200 mm x 1200 mm, scanned at a resolution of 400 dpi would take 30 minutes to scan in colour mode and produce an uncompressed file of about 340 MBytes.

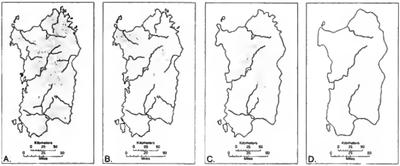


Figure 4.14 Increasing Digital Simplification of the Coastline and Hydrology of Sardinia (from Robinson, 1995)

Scanners are ideal if the purpose is to capture all the information from a paper image or map, or if you wish to add information to an existing base map. Scanning is also a useful method of archiving existing maps.

There are a range of scanners all of which use photosensitive pick-up devices to register different grey or colour tones from the surface of a map (or any document). Hence they convert an analogue image into a digital image. Data is stored as a raster image via pixel values which vary with differences in light intensity. Most scanners are capable of 8-bit resolution, or 256 brightness levels. There are software programs which convert the raster image into a vector format. This may be necessary if topology is to be added to the scanned data. Some of the main scanning devices and methods available include:

i) Flat-bed scanners having a photosensitive pick-up which is mounted on a beam allowing the pick-up to traverse the map along an x axis. Meanwhile the whole beam is able to move slowly along a track in the y axis direction (Figure 4.15 a). Resolution is typically 600 dots per inch (dpi). Prices start from about US$1 000 for an A4 mono version.

ii) A drum scanner uses the same process as the flat bed scanner except that the map is mounted on a drum which slowly revolves beneath a fixed track upon which the pick-up rides backwards and forwards in the x direction (Figure 4.15 b). On both flat-bed and drum scanners the step size between each row controls the cell or pixel size, which is typically 0.025 to 0.050 mm.These scanners are at the top end of the scanner price range, and have resolutions of 400-800 dpi.

iii) The continuous feed scanner (Figure 4.16) is a further scanner which operates on similar principles. Here the map or document to be scanned is fed past a fixed row of sensors each of which record an image intensity. Accuracy is not yet as good on the flat-bed or drum scanners, hence they are sometimes referred to as "document scanners". They can produce mono or colour output at resolutions up to 400 dpi. Prices for A4 models again start at about US$1 000.

iv) There are now available small hand held, or desk top, scanners. Some of them can produce true 24 bit colour at resolutions of 400 dpi. However, despite the claim of having sets of rollers for straight scanning and warning lights regarding scanning speed, care should be taken in doing GIS work since distortions are almost inevitable given some "hand wobble" and variations in scanning speeds. Prices start from just over US$100.

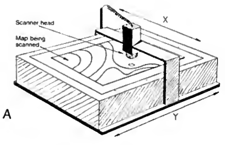
v) Scanning is also possible via electronic video-digitising. Here a normal video camera captures images as collections of up to 512 x 512 pixels each containing a level of light intensity. This is a cheap form of data capture but the resolution is poor.

vi) An automatic line scanner can be employed to do the job of a digitiser. Here a narrow laser beam automatically follows a line on the map until the line ends or a junction is reached when the operator must intervene to redirect the process. Greater accuracy can be obtained than from manual digitising and it can be faster, but it is user/time intensive compared with other scanning methods.

vii) Drummond (1992) describes the process of "on-screen digitising". Here the scanned image is displayed on a screen and the operator follows any desired lines on this image by the use of a refined screen cursor which can digitise in point or stream mode. Obviously the vector lines produced can be made "intelligent" by also capturing any attribute data.

viii) Lever (1993) reports the impending use of imaging technology. This essentially means that scanners will be able to be pre-set so as to only capture data from a map which is of a given reflectance value, i.e. allowing separate layers to be built up based on the different colours of an analogue map.

There are a number of drawbacks to scanning. Scanners can be said to produce an "unintelligent" image since they have no means of differentiating between different types of map features, i.e. unlike digitising, they cannot add attributes. This problem can sometimes be overcome by scanning from the original colour print masters. Scanners also sense everything which is on the original map including labels, stains, wrinkles, etc. This can mean that extensive editing is necessary, i.e. unless the map has been purposefully drawn. Obviously, scanning also produces very high data quantities which need expensive storage. Many commercial scanning companies now operate who can offer expertise, and given the cost of good scanners, then this is frequently a sensible source for obtaining digital outlines. A summary of scanning devices and methods is given in Devereux (1992,b) and Dickinson and Reid (1992).



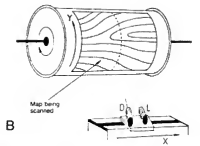


Figure 4.15 **Diagrammatic Representation of Flat-Bed Scanning (A) and Drum Scanning (B)**

4.6 The Integration and Processing of Other Digital Data

In Chapters 2 and 3 it was made clear that a large amount of data was available which was already in a digital format. Most of this data was from RS or hydro-acoustic sources. Here we will be concerned with some of the main processes which might need to be performed on this raw data in order that it can be readily utilised by a GIS. These operations might be called post capture processing or more usually image processing. Some of the processes performed on aerial photographs were briefly mentioned in section 2.3.4.3 and Cassettari (1992) gives further details. Much of the processing can actually be performed as part of the existing software routines within the more sophisticated GIS packages, otherwise there will be specific software available which carries them out.

Since the use of existing digital data from sources such as RS, digital photogrammetry, hydro-acoustic surveys and aerial videophotography is likely to greatly increase over the next decade,

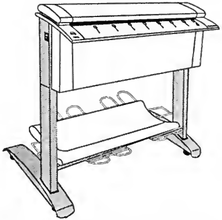


Figure 4.16 An A0 Size Continuous Feed Scanner

integrated image based systems which link the necessary image processing with GIS are likely to develop. Edwards et al (1990) and Faust et al (1991) outline many of the benefits to be obtained, and Cassettari (1993) suggests several ways in which this integration might progress, e.g.

(a) GIS software packages might include all the necessary functionality, although the majority of GIS users are likely to find many of the routines too complex.

(b) Individual GIS software developers could take the modular approach so that buyers would only purchase the functionality that they needed or understood. Each module would be transparently integrated with each other.

(c) Present GIS software producers could enter arrangements with image processing software houses to ensure that their packages were fully compatible.

(d) An open systems environment where multi-tasking can be operated (Figure 4.17). Here, through the use of windows, several displays could be made together, e.g. an RS image, a map and a photograph. The user can choose the data to be displayed and comprehensive menus help with any necessary processing.

Despite these positive approaches to the integration of RS digital data into a GIS, there are undoubtedly still many problems to be overcome before the requisite tasks can be routinely performed. For readers wishing to know more, the problems have been clearly set out by Estes (1992).

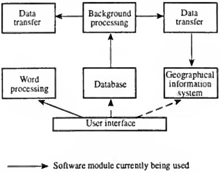


Figure 4.17 Integrated Spatial Information System Based on a Multi-Tasking Environment (from Cassettari, 1993)

The degree to which raw RS derived reflectance values need to be processed depends on the ultimate use of the digital data. Thus, for instance, if the images are simply to be used as a "back-cloth" or drape behind a vector foreground map, then minimal image processing is necessary, i.e. basic ortho-corrected imagery is required and for this the basic software is readily available. For those interested, Cassettari (1992) and Havercroft and Fox (1993) suggests ways of accomplishing this. But for other purposes it might be necessary to refine the image to an extent whereby a great amount of accurate detail can be extracted. Figure 4.18 gives a fisheries related example of the type of hardcopy output which can be obtained once processing has been performed. These images were produced by the Atlantic Centre for Remote Sensing, using water temperature data obtained from the NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite sensor. The following pre-processing functions are not described in great detail since in practice they are best accomplished by image processing experts.

4.6.1 Radiometric Correction

The reflectance values capture by any RS system will suffer changes or distortions over time for a number of reasons, e.g. by the presence of aerosols in the atmosphere, by the effect of variable relief on reflectance, by changes in the attitude of the sensing platform, from changes in the angle of the sun or slow changes in the functionality of detector sensitivity. There are a number of radiometric correction measures which may be applied, with each being based upon a different assumption or model, some of which are described in Butler et al (1988). The aim of the measures is to achieve uniformity of pixel value representations across the image.

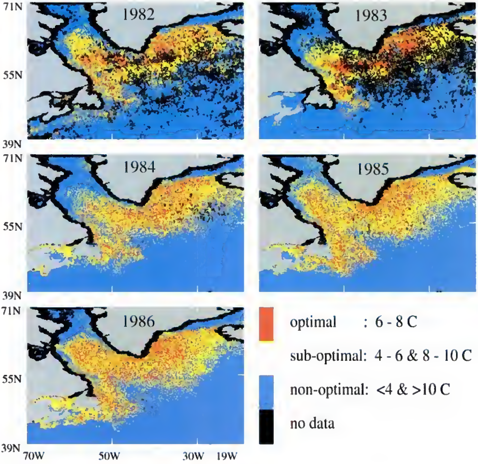


Figure 4.18 Optimal and Sub-Optimal Habitat Conditions for Atlantic Salmon in the North West Atlantic Ocean

4.6.2 Geometric Correction

This pre-processing can also be necessary for a number of reasons, e.g. changes in the velocity, altitude or depth of the sensing platform, any oblique angles used in collecting the data, the earths curvature and rotation, atmospheric refraction, satellite instability, etc. To effect geometric correction it is necessary to follow a logical sequence of processes which gradually ensure that the registration of the image is accurate. The level of accuracy can often be verified using a sufficient number of ground control points which are readily identifiable on both the digital image and a map. Geometric correction of a large surface area will need to be performed using different mapping projections, e.g. Mercator, Peter's, Conformal Lambert, etc.

4.6.3 Image Display and Enhancement

There are a large number of functions which can be performed on digital data in order to meet particular requirements. These functions will enable the image to acquire specific characteristics which may be necessary to fulfil a special task. Table 4.3 briefly describes some of the main methods used to enhance satellite RS imagery. Further details can be found in Serra (1982), Niblack (1986), Jensen (1986), Gonzalez and Wintz (1987), Harrison and Jupp (1990) and Cracknell and Hayes (1991).

Table 4.3 Some Image Enhancement Processes Which May be Applied to Raw Satellite Sensed Digital Data

ENHANCEMENT METHOD	RESULT ACHIEVED
Contrast stretching	Reflectance values are changed, using a linear, uniform, gaussian or other stretch, so as to occupy the full value range.
Edge enhancement	Known or perceived boundaries, which do not show up clearly on the image, can be more clearly displayed.
Density slicing	The computer software assigns thresholds and colours to different classes of pixel values.
Spatial filtering	Low pass or high pass filters can suppress or enhance pixel values in an image.
Principle component analysis	This compresses multi-spectral data sets as an aid to image classification and pattern recognition.

Image classification	Here the software is "trained" to detect spectral signatures for one area, which have been ground truthed and therefore known to be true, and then apply it across the image.
Change detection	Data sets collected at different dates or times can be registered and compared pixel by pixel to work out rates of change.
Digital mosaics	This is simply the "patchworking" of different images to produce one clear image of a large area.

CHAPTER 5 - HARDWARE AND SOFTWARE NEEDS FOR A MARINE FISHERIES RESOURCE GIS

5.1 Introduction

Given that the range of both hardware and software which could be incorporated into a marine fishery resources GIS is extremely large, it is important to mention how our discussion of this will necessarily be limited. Firstly, we shall only discuss hardware and software which is directly relevant in the sense that it would be both very useful to a marine fisheries GIS and that it could be considered as being within the working sphere of most GIS operators. Secondly, detail will not be given on how any piece of hardware actually works, i.e. our concern will be primarily with its usefulness, any limitations and its performance. Finally, it will not be possible to consider a whole range of different models of specific hardware items - we will restrict ourselves to "core items". Readers who wish to obtain further information on hardware for GIS's could refer to Carstensen and Campbell (1991) or Faust et al (1991), plus specialised hardware and peripherals trade magazines. Further information on software can be obtained from Cambridge Market Intelligence (1993) and some of the other trade sources shown in Chapter 8.

It is pertinent to mention that the substance of most of this chapter is likely to date quickly. Technological advances in almost all areas of computing are such that new types of hardware, refined models of existing hardware and falling prices, are all occurring at a rate which could make much of this text obsolete in two to three years. As Frank et al (1991) have noted,

"There are no indications that the speed of this development will decrease in this decade. Even though there are ultimately physical laws that will limit speed and miniaturization, such as the speed of light and the need of at least one electron to store one bit of data, these limits are far beyond current technology."

A similar revolution is also occurring in software development, with the major software houses constantly bringing out new versions of existing packages. To exemplify this rapid rate of GIS technological advancement, Table 5.1 shows that we are already in the so-called 5th generation of GIS's.

Throughout this section we will attempt to give indications of current purchase prices (in US$) of typical equipment or software described. Clearly these are only indicative and they will be subject to variations for a variety of reasons. Additionally, it will be clear that there will always be extra costs to consider such as peripherals, consumables, servicing, operator time, insurance, depreciation, etc. It is also important to remember that, for most hardware items, there are many manufacturers and that there are not yet any standards with regard to ensuring compatibility between hard and software. So, if buying a plotter for instance, where Hewlett-Packard (HP) are one of the leading makers, then make certain that your plotter includes drivers which emulate the HP. Although we can advise on plotter and printer prices, before purchasing a particular hardware item the buyer should also enquire about the output price per hard copy sheet.

Table 5.1 Characteristics of the GIS Eras (as recognised by Antenucci, 1993)

Circa	Document Platform	Generation	Processor Configuration	Database Configuration	Data Model Graphic	Data Model Attributes
1968-1975	Mainframe	1	Centralized	Centralized	Raster	Flat file/ hierarchical
1975-1982	Mini-computers	2	Centralized	Centralized	Raster	Hierarchical -relational
1982-1988	Workstetions/ PCs	3	Partially distributed	Centralized	Vector	Relational
1988-1992	Workstations/ PCs	4	Distributed	Partially distributed	Vector	Relational
1993	Servers/ Workstations/ PCs	5	Distributed	Distributed	Vector/ Raster	Relational

5.2 The Major Hardware Items for a GIS

We should initially remind readers that in Chapter 2 many of the hardware items which are associated with data gathering have already been discussed, and in Chapter 4 we described the essential hardware which are used for GIS data capture and inputs, i.e. digitisers and scanners. This means that the hardware discussed here will be that associated with computer processing, data storage and the various means of obtaining GIS output. Some points to consider before purchasing any hardware are discussed in section 8.2.4.1.

5.2.1 Computer Processing Units

Many readers will aware that the processing hardware (the computers themselves) have conventionally been classified under headings which broadly reflect their processing power. Thus processors range downwards from mainframes to minicomputers, to workstations, to micro or personal computers (PC's) and finally to lap-tops or notebooks (Table 5.2). We will not undertake a separate description of lap-tops or notebooks, since apart from their portability and mains free independence, their specifications and functionality are virtually the same as micro-computers. Originally GIS software was designed for use on the larger processors but recently there has been a marked movement towards supplying software which is specifically aimed at the smaller processors. Thus Maguire and Dangermond (1994) illustrate the changing importance between the three main types of processor units (Figure 5.1). This change has been a response to the fact that the performance/cost ratio of personal computers has undergone dramatic improvements, especially during the last five years, and advances in technology have tended to blur the distinction between the levels of processors. A PC today could out-perform most mainframes of 15 years ago, and most workstations of five years ago.

Table 5.2 A comparison of processor units (after CCTA, 1993)

Processor Type	Number of Users	Main Memory	Role	Cost Range (Sterling)
Mainframe	More than 256	64MB+	Volume processing	£250K plus
Minicomputer	Up to 256	8MB-256MB	File server	£50-£250K
Workstation	Single user	4MB-64MB	Stand alone	£3-£50K
PC (including lap-tops)	Single user	1MB-16MB	Stand alone or single user node on network	£1-£5K

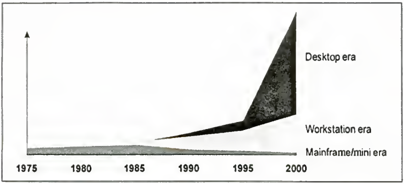


Figure 5.1 The Changing Importance of the Three Main Types of Computer Processing Units

For GIS purposes alone a mainframe would seldom be necessary, though some of the more complex packages function optimumly on them. A mainframe would usually only be used if it were already available in an establishment and if the task warranted its use. With the present status of marine fishery resources GIS it is unlikely that there would be many datasets available or tasks which were required which would necessitate access solely to a mainframe. However, with the rapid build up of datasets resulting from oceanographic remote sensing capability, from

other oceanographic research activities and from the increasing need for 3-D or 4-D applications, perhaps using acoustically acquired datasets, then the need for future access to a mainframe might be desireable. But whether this need will grow at a faster rate than improvements in the technology or capability of the "smaller" processors it is difficult to forecast. So presently, for most conceivable large applications of a marine fisheries GIS, a minicomputer would provide sufficient functionality. As Table 5.2 infers, minicomputers may be functionally conceived of as small mainframes.

For most serious GIS applications a workstation would be a logical choice, and indeed much of the GIS software is currently supplied to function on specific models. Most workstations have a 32-bit architecture, a large main memory and storage capacity, use the UNIX operating system and would utilize a high resolution graphics screen of typically 21" dimension, often in association with a mono screen to display the current processing status. They typically function as stand alone systems though they may be integrated on to some a network if required (see Section 5.3.2). Frank et al (1991) envisage that by the late 1990's the average GIS workstation will have the following specifications:

* A processing unit having 500 MIPS (million instructions per sec.
* 500 Mb of RAM memory.
* 5 Gigabytes of storage space on internal hard disks.
* An additional 50 gigabytes of memory on external optical disks.
* A workstation screen with a 2 000 by 2 000 pixel display.
* A communication device with 100 megabits per sec transfer rate.

The main growth area in GIS, with regard to the numbers of software products sold, is in the PC (or micro-computer) range. This range incorporates a huge variety of brand name processor products, most of which can be classified as either being PC's or Apple Macintosh's (MAC's). The former usually operates under the MS-DOS system, uses an Intel chip and they are said to be IBM compatible. MAC's use Motorola micro-processors and have their own propriety operating systems, though MAC's which can also run under DOS are now available. In view of the large potential data inputs, and GIS requirements for copious mathematical calculations then, if a micro-computer is being considered for marine fisheries GIS purposes as a stand alone machine, certain minimum size requirements should be recognised. For instance, for a PC at the present time, an 80486DX chip with a speed of 50MHz, at least 8MB of internal memory (RAM), a 200 MB hard drive plus a 16-bit SVGA high resolution card with a suitable colour screen, would all be minimal necessities. Ideally a more powerful processor would be recommended but decisions on this would accord with the scope of the GIS envisaged. Obviously, the purchaser would also need to consider such things as the number of expansion slots, the size of cache, the size of floppy disk ports, serial ports, parallel ports, etc. For most GIS purposes, we would not recommend consideration of lap-top or notebook computers simply

because the screen size can only give a limited visual image. Finally, we envisage that there will be a blurring in the distinction between PC's and workstations, i.e. there will be a continuous range of computers from small PC's through to large workstations.

5.2.2 Visual Display Units

As with other computer technology, but perhaps not so noticeably, Cathode Ray Tube (CRT) display has been advancing rapidly. High resolution displays with a dot pitch of >0.28 mm are now usual for most PC screens, giving a standard resolution of 1024 horizontal dots in 768 vertical lines. With the larger screens on most workstations there may be a 1600 x 1280 screen dot image. Screens now have "non-interlaced scanning" which gives a flicker free display, and screens will commonly have low-radiation, anti-static and anti-magnetic features. The colour capability is now vast such that 24-bit memory allows for the potential display of 16.7 million colours, though the capability of the programme may restrict the colour range. Screens can now be commonly transferred between different computing environments, i.e. since they support an array of graphics adapters (typically IBM MCGA, VGA, 8514A, XGA, Apple Mac II and VESA). Costs vary from about US$1 000 for a 17 inch screen to US$3 000 for a 21 inch screen, though most low cost standard 14 inch modern screens can also be used.

5.2.3 Storage Devices

In this section we will not be concerned with the working memory or random access storage (RAM) - we are only concerned with secondary storage. It is useful to note that secondary storage functionally comprises of two activities:

a) The storage of computer programmes, or sometimes datasets, which have usually been purchased and which consist of data which remains unchanged, i.e. read only material.

b) The storage of files which usually consists of work being done by the computer user and which could be constantly changed.

This distinction is important because some storage devices will only cater for (a) above.

Most computer users will be familiar with the fact their data is normally stored on 5.25 or 3.5 inch "floppy" disks or on the processor's internal hard disk drive. Floppy disks have an extremely limited data capacity (1.44 MB for a high density disk), though hard drives for PC's may range upwards from 10 MB to at least 5 GB (5 000 MB). Obviously the storage capacity on larger processors is much higher and the actual amount stored may reflect the specific configuration in use. Storage capacity is required not only as a primary depository of data but also as a back-up for this data.

An external hard drive is sometimes favoured. This may be a simple way of extending the processors capacity, i.e. if the processor has insufficient room for adding extra data storage or as a way of storing data separately from the main computer in case of an computer "crash". This device often acts as a back-up storage system, i.e. for the duplication of files. Storage costs using a hard disk work out at about US$1.50 per megabyte.

Large volumes of data, usually that used on mini-computers or mainframes, may be stored on a tape drive. These are either magnetic tape cartridges or reel to reel drives. These portable storage methods allow for off-line storage, i.e. when a particular tape is required it must be retrieved and accessed to the processor. Digital Audio Tapes (DAT) and video cartridges are becoming more popular because of their capacities and compactness. Magnetic tape is the cheapest form of digital storage with costs working out at about 5 cents per megabyte.

Another storage medium for accessing large volumes of data are CD-ROM's (compact disks - read only memory). CD's are optical disks which incorporate laser technology, and they are capable of storing huge quantities of data on their three mile long pitted spiral surface, i.e. each disk can store up to 650Mb. This efficient storage medium means that, as their speed of operation is now increasing, thanks to double or quadruple data transfer rate times, then they could become the software source format for all larger programmes in the near future. One of their main advantages is that they are easily archived and transportable. Optical disks which run on the conventional CD drive are now available which can be written to, edited and then re-written. Many micro-computers are now being sold with CD-ROM drives installed and many larger GIS datasets are being released on CD's.

5.2.4 Printers and Plotters

The range of printers and plotters is now very large indeed. Our sub-headings here reflect those which are commonly used, but these output devices could be classified differently. Indeed, in the literature there often seems to be no clear distinction between the term "printer" and "plotter". Before any decision is made to invest in any of the output hardware described, the final user would need to think carefully about factors such as the speed and throughput of output, the nature of the output involved, special paper and ink requirements, plus the size, type, quality and volume of this. Details on plotter selection are given in Thomas (1993) which also provides details on plotter price and performance (Figure 5.2).

5.2.4.1 Dot-matrix Line Printers

These are low cost, and therefore popular, devices which may be used both for the high volume output of textual documents or for slower output of graphical material including maps. Output is typically at A4 size though many devices can easily produce A3 size or longer output on continuous traction paper. Printing speeds for textual material varies from 300 to 2000 lines per minute depending on the quality of the device (plus its printer settings), the software being used and the quality and size of the fonts being currently used. Graphical output is usually slower. Here, the software organises the output so that it is printed sequentially line by line. Output is via a series of dots with the resolution being limited by the density of pins on the print head - it is typically in the range of 70 to 150 dots per inch. Some of the older graphical packages used to obtain shading density from line printers by varying the combination of alphanumeric letters which they printed. Multiple colour ribbons can be used to produce a limited range of colours.

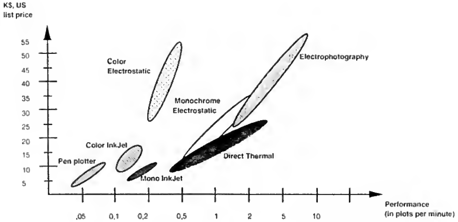


Figure 5.2 Plotter Technology: Price Against Performance

Output from dot-matrix machines is relatively crude, and noisy, but these drawbacks should be measured against cost advantages. Costs per machine vary within the range of US$200 to US$500.

5.2.4.2 Laser Printers and Plotters

Using laser technology, these printers are capable of very high quality, almost silent output of both textual and graphical information. Until recently most output was limited to black and white shades but colour models, at rapidly falling prices, are now available. The size of machines varies considerably, from low cost A4 models (desk-top or portable) having an output of about 15 pages per minute and a resolution of 300 dots per inch, up to large A0 printers with a variable resolution of from 400 to 600 dots per inch. A4 laser printers can now be purchased for US$600, but laser plotters will be more expensive, e.g. a typical A3 laser plotter would be US$6 000 but an A0 model could be in excess of US$45 000. Output from top end laser plotters would be equal to that achieved from conventional offset printing.

5.2.4.3 Ink-jet Printers and Plotters

These devices fill a similar niche as the laser printers, with the difference being that they are usually cheaper to purchase being based on a different technology. Output is obtained by forcing ink through small nozzles to form microscopic droplets which strike the printing media in combinations determined by the printing commands. By mixing any combination of four basic colours via multiple nozzles, an almost infinite array of colours can be achieved. The resolution varies from 120 to 300 dots per inch, though the newest A0 ink jet plotters have a resolution of 720 dots per inch. Printing speeds may be comparatively slow but with recent improvements in price, speed, resolution and reliability they are now extremely popular as a GIS output device. In fact, we would envisage that in the immediate future, with the reduction of "fuzzy" outlines, then ink-jet technology will offer the best all-round solution to the GIS user's needs. Small colour desk-top ink-jet printers cost about US$500 whilst the A0 size is about US$6 000.

5.2.4.4 Pen (Line or Vector) Plotters

This type of plotting is basically mimicking what a cartographer or draughtsman would be drawing by hand. There are two basic types of pen plotter - drum (or roller) and flat-bed, each of which has particular advantages. Both types utilise cartridge pens, which can be of variable colours or line width, and they both produce vector (or line) output which corresponds to grid co-ordinates held in the computer file to which they are linked. Maximum line drawing speed is about 100 cms per second and "intelligent" plotters can now arrange vectors in the plot file so as to plot them most efficiently. Some top of the range plotters are also designed to operate as precision scanners with a resolution of up to 400 dpi. A major problem with pen plotting has been the need for constant supervision in case pens clog or run out of ink, but unattended pen plotting technology is likely in the near future.

(a) Drum plotters (Figure 5.3) consist of a drum, which can be rotated in both directions, which has attached a continuous roll of paper or other drawing media. The pen(s) moves horizontally in both directions along a carriage to plot lines. Drum plotters vary in width from 25 to 150 cms, and output can be in up to eight colours. Their main advantage is that they can produce multiple plots without the need to feed paper and the plot length is flexible (up to 50 metres). Cost for a small A4/A3 desk-top pen plotter is about US$1 000 whilst an A0 drum plotter is about US$5 000. The newest desktop pen plotters, and some of the larger free standing models, now use rollers (rather than a drum) to move the paper backwards and forwards.

(b) Flat-bed plotters have a flat drawing surface over which the pen(s) can move in x and y directions or in conjunction to produce curved lines. These plotters vary in size from small A4 to larger A0 and the output is again controlled by co-ordinates held in the host computer file. Their main advantage is that they can utilise a wider variety of media, e.g. paper, plastic, engraving foils, or photographic paper, and scribing can be done by several types of pen plus laser implements. Very low cost products (from about US$300) can now be obtained for

Figure 5.3 Typical Drum Pen Plotter

attaching to micro-computers, or which have their own drives which allow the user to simply insert his disk and the plotter will then work from the data stored, i.e. freeing the computer for other work. Top of the range A0 flat bed pen plotters cost about US$4 000.

5.2.4.5 Electrostatic Plotters

These devices, of which there are several sub-categories, operate by using an array of nibs (electrodes) to selectively deposit charges on paper (or film) in the form of an image. Toner is then made to adhere to the charged areas, i.e. in a similar way to photocopying machines. Once the data has been converted to a raster format, images can be output from the plotter at 60 x A0 mono drawings per hour, or 15 cms per second for A0 colour output, i.e. much faster than any pen plotter. Output can be in mono or colour, at any size, and resolution is high at up to 400 dpi. For large format output on a daily basis, this type of plotter might be a realistic option. Although costs have been decreasing, these plotters may still be priced upwards from US$40 000.

5.2.4.6 Thermal Plotters

Direct thermal plotters (Figure 5.4) use local heating to warm thermo-sensitive paper, which is coated with two separate, colourless components. Once heated, these combine to produce a wide range of colours of fair quality. They can produce output, in raster format, up to 15 metres long and have a resolution of over 400 dots per inch. Although they are expensive (about US$12 000 for a A0 wide body colour version) they have several advantages, e.g. no cartridges, toner or ink to consider, no feathering of lines due to ink absorption and they can run totally unattended.

Output rates for a full A0 map can be just 30 seconds, and the quality of this can equal that of photographs. Smaller A4 and A3 colour thermal printers are now available which utilise a similar technology and cost upwards of US$5 000. Figure 5.5 compares approximate total plotting costs for an inkjet plotter (HP DesignJet) compared with a direct thermal plotter (Oce G9000). These lower output costs plus lower operator costs and faster output compared with inkjet plotters must be placed against the higher initial purchase price.

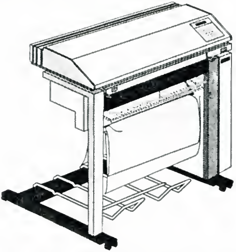


Figure 5.4 Typical AO Thermal Plotter

5.3 Hardware Configurations

Having discussed some of the major hardware requirements, we are now in a position to give some ideas on the selection and arrangements of the various hardware components, or the GIS "architecture" or "configurations" as they are sometimes called. We discuss configurations which progress from the simple to the more complex. In doing this there should be no inference that systems progress from "bad" to "good" or from "make do" to "ideal". Clearly, the choice of systems architecture will be a reasoned judgement reflecting particular circumstances relating to personal preferences, finances available, any functional requirements, the number of users and the required degree of interaction with other systems. Whichever type of configuration chosen, there will always be the possibility of additions to, or upgrading of, the existing facilities. In Chapter 8 we discuss further the task of systems selection.

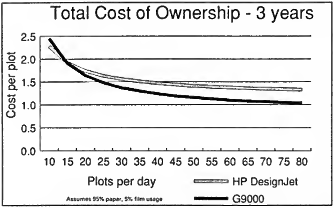


Figure 5.5 A Comparison of Operating Costs Over Three Years for Inkjet v. Thermal Printing Technology

5.3.1 A Personal or Stand Alone System

The minimum hardware configuration can be met by having a processor (PC, Apple Mac or a workstation) linked to an output device, usually a laser or inkjet printer or sometimes a small pen plotter. This configuration could allow for a wide range of output to the screen, for saving to disk or in hardcopy format. However, the input of data to the system would be limited in the sense that it could only consist of tabular data, which may be stored in a spreadsheet or in a database package, or data stored on a floppy or CD-ROM disk which might have been purchased as a ready made data set or had been captured via a data conversion company (or via any other agency). So if the regular interchange of data is envisaged, then stand alone systems are not ideal. These systems are also not ideal if speed is required or if large data sets are to be handled. However, additional functionality can be obtained by adding a digitiser, or a scanner to a stand alone system so that user defined mapping outlines could be captured. For most stand alone systems it would also be a simple task to expand their functionality by establishing communications linkages to external computers or data sources. The cost of a minimal stand alone system, including software and hardware, would be US$3 000 though it could rise to about US$30 000. Figure 5.6 gives an idea of what this configuration could consist of.

5.3.2 A Multi-user Centralised or Departmental System

This configuration includes a variable range of hardware, usually including a central processor (sometimes called a file server or host computer because part of its function is to facilitate the sharing of the various devices), several PC's or workstations, a printer, a plotter, a scanner and digitising facilities plus probably some external data backup storage device. This system thus

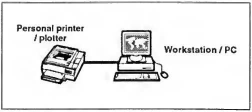


Figure 5.6 A Basic Stand Alone GIS Configuration

becomes a network (usually called a Local Area Network - LAN) and it has distinct advantages, not only in terms of power, but also from the fact that several operations can be performed simultaneously and the expensive peripherals can be conveniently shared (as can any software and indeed any data). The network may also be integrated with other information systems within an organisation. Figure 5.7 gives an indication of a typical departmental system. There are two basic variations of this LAN, each with advantages and disadvantages. The first is where each workstation performs an allocated task having its own data storage and set of software programmes (so-called intelligent workstations), and the second is where all workstations are connected to one main network server on which the software and data is stored. Clearly there are going to be large cost considerations if this type of configuration is installed. These costs are not only for additional hardware, but also the software has to be licenced for each machine on which it is installed, and there are greater needs for database management (see section 6.5).

5.3.3 A Wide-Area-Network or Corporate GIS

Figure 5.8 gives an indication of the possibilities for operating a marine fisheries GIS on a considerable scale and with processing being distributed over a wide spatial area. This configuration becomes an enlargement of the local area network in the sense that all GIS operations can have access to databases which might reside almost anywhere - so-called distributed computing. For example, larger corporations or perhaps government departments will frequently have databases residing in different locations, and microwave transmissions or cable networks allow transference of data between workstations regardless of their location. The wide area network (WAN) can consist of an almost indefinite array of hardware devices. Clearly the advantages of this configuration are in terms of processing power, the rapid access to datasets which are in scattered locations, and the consequent time savings in assembling requisite GIS information. However, these advantages are only gained at some considerable financial expense in terms of expertise, organisation, capital expenditure and data gathering costs.

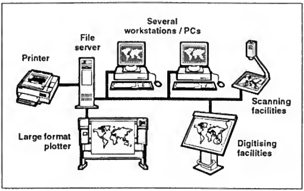


Figure 5.7 A Typical Centralised, Departmental GIS Configuration on a Local Area Network

Most workers in GIS research would contend that the configuration future lies in WAN's. The main reason for this lies in the need to access distributed databases. We are already aware that any fisheries GIS is likely to be involved in a range of different and diverse subject areas (further discussed in Chapter 7), and thus eventually there are going to have to be linkages to other departments or establishments. Table 5.3 gives some reasons why distributed processing via WAN's is advantageous. Laurini (1994) gives an interesting account of some of the considerations in the move towards distributed database use in GIS.

Table 5.3 The Advantages of Using Distributed Computer Capabilities for GIS Work

* Cost and effort savings on the need to duplicate databases.
* Far less total data storage capacity is required.
* Any one database maintains its integrity since it will be in the interests of the holder to maintain and update it regularly.
* Easier for users not having to maintain security over their databases.
* Data in effect becomes both local and international.
* Access to distant data becomes easy.

5.4 GIS Software

Since there are no logical ways of examining GIS software then, after a brief introduction, this section will seek only to (a) discuss some of the varied characteristics of the software in general

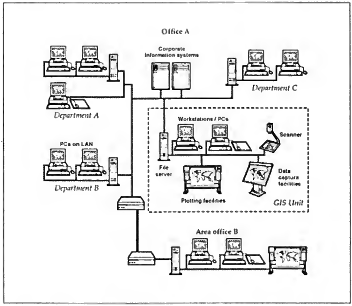


Figure 5.8 A Wide Area Networked GIS Configuration

and (b) examine in some detail a range of specific GIS packages. It is important to point out initially that we will not be looking at types of software that are ancillary to GIS yet which, in some cases, may be vital to its success, e.g. we will not consider any operating systems, any image processing packages, any graphical enhancement or drawing packages or any specific database management programmes (though the latter will be mentioned in Chapter 6). It is also important to note that there is no exact definition of what GIS software is! With this in mind we will also not be including here considerations relative to:

* Database management systems (DBMS).
* Cartographic (mapping).
* Computer Aided Design (CAD).
* Remote sensing or image processing.
* Digitising programmes.
* Contouring and surface modelling.

i.e. even though any of these elements might be incorporated within many GIS software package. Some points to consider when purchasing software are considered in section 8.2.4.2.

Until the late 1980's, one of the main criteria upon which the choice of GIS software was made, was whether the system was raster or vector based. Until then it would be true to say that vector systems, though often more expensive would generally have been preferred, i.e. given the types of use for which most earlier GIS's were acquired, plus their ability to provide a better looking final output and the lack of affordable raster data or methods of data capture. However, since then the balance has slowly shifted in favour of raster based systems. This is because:

(i) New computer processing capacity has allowed for easier storing of large raster data quantities.

(ii) VDU's can now display huge arrays of very small pixels, i.e. providing a vary clear eight-bit colour image.

(iii) The resolution of raster scanning devices has dramatically improved, i.e. they are now able to scan at 1000 dpi. Once scanning is above 500 dpi it is difficult to differentiate between raster or vector lines.

(iv) The quality of scanned raster data, using various collection techniques, has greatly improved.

(v) Larger amounts of commercially available raster data are now both available and affordable.

(vi) Progress has been made in raster processing techniques which allow for automatic vectorization.

(vii) Advances are being made in introducing effective standards for raster data handling, interchange and storage.

(viii) Raster images are now frequently being used as background drapes on vector images, i.e. in order to aid visual interpretation of user data.

5.4.1 Some Varied Characteristics of GIS Software

Since software characteristics are so varied, we can only attempt here to offer some insight into a few of the ways in which packages differ. It is important to know something of this because, given the range of GIS software which is available, it will pay the prospective purchaser to be familiar with some of the differentiating factors which need to be borne in mind before investing in a particular software system.

5.4.1.1 Variations in the Components of a GIS Software Package

GIS applications software consists of multiple programmes which are integrated so as to ensure the capabilities of mapping, managing and analysing geographic data. The balance of the programmes in the package may be biased towards the database management side or towards graphical presentation, etc, i.e. according to the particular market niche which the software is aimed at. There are also specialised packages which may be marginal to GIS which highlight certain areas such as network analysis or terrain analysis. Basically the GIS software should allow for a minimum of:

(a) Graphical data entry - allows the inputs of map features in the form of geo-referenced locations.

(b) Annotation entry - allows for textual information to be displayed on maps.

(c) Graphic editing - allows maps to be updated or amended.

(d) Data manipulation - allows the data to be manipulated in some or all of the ways outlined in Section 6.2.

(e) Graphic display - allows for control over the appearance and format of maps.

(f) Database management - allows for the entry, storage, retrieval and management of information relative to the graphical entries.

The software must have a language by which queries are made (usually Standard Query Language - SQL), and some form of user interface. The software should also support a wide range of peripherals through having the relevant drivers, i.e. the routine that handles the specific details and characteristics of a single peripheral device so that it can work correctly. Most software is now produced to meet with official or de facto standards, e.g. most important for GIS software is ISO 8211. These standards have been adopted to regulate the way in which the broad GIS community of vendors and users operates

5.4.1.2 Variations in Software Evolution

The first specifically GIS packages were produced in North America during the late 1970's. Their evolution and categorisation has been complex. One of the main reasons for this is that it is still difficult to accurately define what is, or is not, GIS software. For instance, there are many mapping packages available which have varying degrees of functionality and obviously some of these packages will offer peripheral or part GIS capability. There are possibly 60 to 80 true GIS packages which are now commercially available; indeed Cassettari (1993) lists 42 GIS packages which are available for microcomputers. There is also a large amount of GIS software which was originally designed for a particular purpose, but which has later spawned a new and similar commercial package, e.g. if one electric utility company acquires a purpose built GIS then this product is often suitable for other electric utilities.

Much of the software capability has evolved from Computer Aided Drawing (CAD) packages in conjunction with the field of computer graphics. The RS industry has more recently given the incentive to integrate much image processing capability into GIS software. And most recently, as has been argued by Antenucci (1993), it is database capabilities which are the driving force behind GIS software evolution. Whereas once software was either dominated by a raster or vector data storage considerations, packages are increasingly able to cope with both of these. The market for GIS software has been growing worldwide at about 15% per annum for at least the last five years.

It has been argued by Frank et al (1991) that GIS software development is a major problem and that its rate of development has been considerably slower than that for hardware. This has led to both an increase in prices and a poor record of reliability including on time product development. The authors suggest that, because of the poor product development record, many of the software sub-systems, e.g. programming languages, database management systems plus operating systems used, are quite dated. It is actually unlikely that most users would have noticed this "software crisis", i.e. since new software versions are always entering the market,

since user interfaces have greatly improved and because many users are aware of software developments which are taking place such as research into and implementation of object oriented database management systems

5.4.1.3 Variations in Software Companies

Most of the GIS software has originated from the USA. Here there are two main classes of legal ownership, i.e. that in the public domain (government funded and researched) and private ownership. This has caused major problems in the past since public domain software has been sold at prices which cover little more than marketing and distribution costs, and since these products have sometimes been acquired by private companies for integration into their packages. This problem is now diminishing rapidly as commercial software prices have generally fallen and as public domain suppliers have sought to make greater financial gains from their products. There are now about half a dozen major private software houses, which have grown rapidly in size through both sales growth and company mergers, plus dozens of minor more specialist companies. The two largest GIS software suppliers on the world market are ESRI and Intergraph, who between them have 44% of this market (Frost & Sullivan, 1994). Some of the main suppliers are also the public domain companies who exist in Europe as well as in the USA, e.g. ILWIS in the Netherlands and GRASS and IDRISI in the USA.

5.4.1.4 Variations in Product Range and Prices

It is difficult to describe the software range since it is so vast. Products which are purely raster based tend to be cheaper since it is far easier to programme the software. This means that lower end raster products which have emerged from public domain sources can still be purchased from about US$150, though prices vary according to the status of the purchaser. At the other end of the "off the shelf" market, there is software which is designed for use on mini or mainframe computers, or high end workstations, using the UNIX operating system and which has an extremely wide functional range working in both a raster and vector format. Prices here might be in the region of US$10 000. It is fair to say that most software has been designed with a bias towards certain types of operation. Some examples would be:

(a) Products that accentuate their RS integration capabilities.
(b) Products which are particularly suited to environmental work.
(c) Products which are described as "desk-top mapping" packages.
(d) Products which are best suited to GIS training or research.

Certainly, no two GIS software packages would be anything like one another and this makes comparisons very difficult. Additionally, as hinted above, many of the larger GIS's are specifically designed for individual purposes. A recent trend being followed by many of the suppliers is to offer their software in the form of a number of separate modules. This partly results from the fact that the software was becoming too complex, i.e. offering an incredible breadth of functionality, and most users do not require this, although it is also a way of selling a wider range of products.

5.4.1.5 Variations in User Interfaces

The user interface is important in that it determines how effectively the user can work with the system. Thus it should hide internal details so that the GIS tasks become the focus for attention. User friendliness varies quite substantially between packages, i.e. though most now have menu or icon systems, some still require a complex command language structure to be learned. The learning process for some systems may take many months, though this depends largely upon whether learning takes place via gradual familiarization with use or via attendance at a specific GIS training course. Unfortunately, some of the menu driven interfaces are still very complex so learning is still slow. This is often because insufficient thought has been given as to how the typical GIS user thinks, and thus how individual menu items should be grouped. What needs to be done in a computing situation as complex as that of many GIS packages is to design the user interface first, and then integrate it into the software. Raper and Bundock (1993) give an excellent account of the variability of graphical user interfaces, and the importance of developing GUI's which are both easier to use and able to be user customised.

5.4.1.6 Other Variations in GIS Software

These can be most usefully listed:

(a) Some have internal database management systems whilst others do not.
(b) Their ability to service a range of hardware devices varies.
(c) The range of product support and training varies greatly between suppliers.
(d) Some systems require the use of two screens (VDU's), one for the graphics and one for the textual command information.
(e) Some systems can accept user programme modules as well as those that already integrated into the software.
(f) Some systems have windowing capabilities which allow for two or more areas of interest to be displayed on the screen at one time.

5.4.2 Some Examples of GIS Software Packages

We have chosen five GIS software packages as examples. Our selection was simply on the basis of exemplifying a range of packages in order to give the reader some familiarity, not so much with what they can each do, but more with how much they vary from one another, i.e. in order to get some appreciation of the care necessary in selecting a GIS. One of the packages chosen, Intergraph's I/SEA VUE, is not a full GIS but it has been included as an example of the many specialist packages which are becoming available which can sit comfortably alongside a marine fisheries GIS.

5.4.2.1 ARC/INFO

ARC/INFO originated in 1982 and is now one of a range of GIS products produced by the Californian company Environmental Systems Research Institute (ESRI). It is a "top end" product

which was designed to function on mainframes, mini and workstation computers but which can now also be used on PC's or indeed in a mixed machine environment consisting of a network of virtually any combination of GIS related hardware devices. The system originated as a pure GIS tool with the ARC software component being used to manage cartographic data and INFO used to manage the tabular attribute data. ARC/INFO has an extensive functional capability including some 2 500 geo-processing tools. It can support both centralised and distributed databases and its open architecture means that it can be readily linked to other software. The latest versions have a convenient GUI, via a suite of menus, called ArcTools. This was very necessary since originally ESRI were comparatively slow to adopt a simple GUI, which meant that a lot of prospective customers were deterred by the complex command language which formerly had to be learnt.

As with other major GIS suppliers, ESRI have now modularised ARC/INFO so that its GIS capabilities are available via a number of smaller, more specialised packages such as ARC/Cad and ARC/View, all of which share similar database handling capabilities. The company are also offering ARC/INFO as part of a number of integrated turnkey packages. This means that the certain of the software components are combined, together with the requisite hardware, to form a specialised total package for such applications as land and property management, highway information systems, map management and production or various census applications. Many of these specialised application areas represent those which would have similar types of data inputs, e.g. inputs for a census application would all be in the form of tabular numeric data which was geo-referenced to varying levels of the census enumeration district hierarchy, i.e. in terms of most of the mapping, this would be simply relating numbers to unit spatial areas. A further move by ARC/INFO is towards the greater demands for spatial analysis and spatial decision support tools rather than GIS applications which were based on simple inventory monitoring and reporting. New versions of ARC/INFO come out almost every year, and ESRI hold an annual users conference in Palm Springs, California. Prices for ARC/INFO vary enormously according to what you buy and who you are - for a main frame version they might be US$15 000 for the complete GIS, but a PC version for an educational establishment the price is about US$2 500. Figure 5.9 gives an example of the output from ARC/INFO as applied in a marine environmental context.

5.4.2.2 ATLAS GIS for Windows

Atlas GIS was developed specifically as a PC based vector mapping product. It is a top of the range GIS having its own internal database management system, and its makers (Strategic Mapping) have deliberately oriented it towards the business community as a "desk top mapping" tool. Thus it is an off-the-shelf product which comes "bundled" with various "free" outline datasets which are either European or North American based. It is anticipated that many businesses will have either their own customer databases or be able to purchase requisite data sets containing some form of geo-reference (frequently post-codes). These can be simply integrated into Atlas GIS, or the data can be entered via a Lotus type spread sheet, for subsequent mapping. The makers claim that "Atlas GIS for Windows is a way of making GIS a fully integrated tool of the computer desktop".

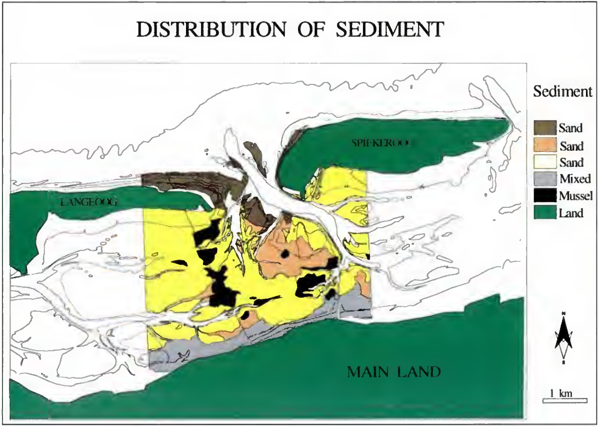


Figure 5.9 **Example of ARC/INFO Output Showing Marine Sediments in Part of the Wadden Sea, Germany (from Liebig, 1994b)**

Atlas GIS has a clear user friendly interface allowing maps to be easily constructed. By clicking on the various menu bars, full menus or windows are opened up, most of which are easy to follow. Figure 5.10 provides a screen image with an indication of some of the ATLAS GIS functionality. Screens can be fully customised. Most mapping output is via density or colour shading, though dot density maps or proportional symbols can be drawn. Maps can be copied to a clipboard and pasted to other Windows applications. Up to 250 map layers can be drawn. One of the drawbacks to Atlas GIS is that it does not support digitising, though there is a DOS version which does. The software runs on an IBM-compatible 80386 PC though a 80486 is recommended (as are 8MB of RAM). The price for Atlas GIS for Windows is about US$2 300.

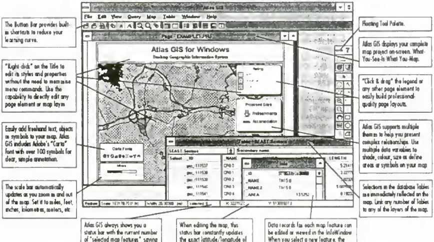


Figure 5.10 Screen Image of ATLAS GIS for Windows Showing Some Main Features

5.4.2.3 IDRISI

IDRISI is a raster based geographic analysis and image processing system, developed by the Graduate School of Geography at Clark University in the US. It is designed to provide a professional level research tool on a low cost, non-profit basis. Since its introduction in 1987 IDRISI has grown to become one of the largest raster based microcomputer GIS and image

processing systems on the market, i.e. accounting for 40% of raster systems worldwide. IDRISI is used for a huge variety of tasks including many under the United Nations Environmental Program (UNEP) GRID programme.

IDRISI is a collection of over 100 programme modules. The modules are linked by a uniform menu system. The modules fall into three broad categories:

(a) Core modules - these provide the fundamental facility for data entry, storage, management and the display of raster images.

(b) Analytical modules - these consist of the major tools for the analysis of the raster data. These modules can be divided into three main groups - geographic analysis, statistical analysis and image processing.

(c) Peripheral modules - these are associated with data conversion between IDRISI and other programmes, data import and export and data storage formats.

By using this modular structure it allows users to develop their own analytical modules which can be linked with programmes in the IDRISI core module. There is also a new interactive digitising module (TOSCA) which supports any digitizer capable of ASCII output. IDRISI is able to run under DOS on almost the minimum PC with only 512K of RAM, a small hard drive and colour graphics card. In late 1994 a Windows version of IDRISI was released, which among many features included a simple means of translating the software into different languages and alphabets. IDRISI can produce raster images of up to 32 000 rows by 32 000 columns and has full vector to raster conversion. It also has import/export facilities to all the major GIS's. This large range of functionality can be purchased at about US$650 for commercial buyers but only US$150 for students. IDRISI also operate a bulletin board which is connectable via the E-mail address:

idrisi@vax.clarku.edu

and they are in the process of setting up a number of IDRISI Resource Centers throughout the world which, operating from local university sites, will be able to offer customers direct training, advice, materials and other services.

An example of output is shown in Figure 5.11 which illustrates high resolution raster output from part of the tutorial package which comes with IDRISI. IDRISI for Windows software system is now available.

5.4.2.4 ERDAS Imagine

ERDAS Imagine is a GIS which has grown from an original image processing package, and it is one of several such packages which ERDAS supply. It is a highly sophisticated raster based product which not only performs all standard image processing and photogrammetric requirements, but which also allows for the overlay of vector data so that both vector and raster analysis, as well as other spatial modelling and map compilation procedures, can be performed. The raster images can be satellite, aerial, photographs or in virtually any form. The GIS has an icon based GUI and it runs on UNIX based systems or in Microsoft Windows NT. ERDAS Imagine consists of six core modules, plus other add on modules. The core modules are:

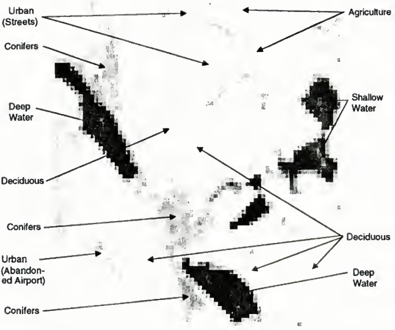
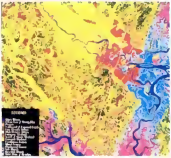


Figure 5.11 High Resolution Raster Output From IDRISI as Used for Pattern Recognition Training

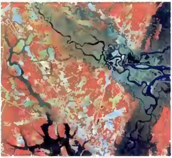
(a) Standard - this is the core of the GIS providing all the input/output capabilities.
(b) Spatial Modeler - this allows raster, vector and tabular data to be integrated, queried and then modelled.
(c) Digital Orthos - this provides photogrammmetric capability allowing for ortho-imagery plus the creation of digital elevation models.
(d) Radar - allows the most common radar datasets to be processed, enhanced and integrated with all other Imagine modules.
(e) Vista - provides access to raster, vector and tabular datasets for querying, processing and composing outputs from anywhere on the network.
(f) Vector - allow for direct access to the ARC/INFO database handling facilities.

ERDAS has been used in a variety of different fields including land classification and land use modelling, vegetation and forest mapping, environmental impact assessment and oceanographic and other marine studies. It is a product which has been used extensively both in the commercial

and public domains, including the UNEP GRID environmental monitoring programme based in Nairobi. ERDAS Imagine is a "top end" product whose price would be in the US$7 000 to US$10 000 range depending exactly on what modules are purchased. Educational establishments can obtain substantial discounts. ERDAS offers other extensive "peripheral" advantages and guidance such as a regular magazine, an educational center in the US and video training packages. Figure 5.12 gives example output of coastal zone monitoring being undertaken in Georgia, USA.



The entire state was divided into 13 major physiographic regions prior to classification. Each of those regions was classified into 12 land cover types. Due to the vegetative diversity within the coastal region, an additional three classes were added for salt marshes (red violet), brackish marsh (light blue), and tidal flats/beach areas (sand).



This false color composite of Landsat TM imagery covers Darien in the Altamaha River Basin of coastal Georgia. The RGB bands (4,5,3) represent lush vegetation as red, water as black, urban areas in shades of blue and the wetlands in brown. Fourteen satellite scenes were classified resulting in land cover maps. These GIS files were output at a scale of 1:24,000 and keyed to more than 1,000 USGS topographic maps.

Figure 5.12 Typical Output from ERDAS Showing Monitoring Processes on the Coastline in Georgia, USA

5.4.2.5 Intergraph's I/SEA VUE

This is a specialist software package for oceanographic and nautical mapping. The software allows for the simple plotting of acoustic echo sounding data in map form. Maps can be presented in either contour or 3-D representations. Since echo sounding techniques produce vast quantities of closely spaced digital data, the software is able to automatically thin out the data

while still retaining all critical information. The software has additional analytical capabilities which allows it to function as a nautical mapping GIS, though the data can be exported to a full GIS for greater functionality. There is a simpler version of the package called I/SEA which is designed to just remove surplus sounding data, thereby creating databases which contain only the soundings for safe navigation.

CHAPTER 6 - THE FUNCTIONING OF A GIS

6.1 Introduction

Almost everything discussed in the previous chapters was necessary to the build up of a functioning GIS, but all the data gathering and digital recording could have been done without a GIS software programme. We have now reached a stage however where all the collected data should be ready for use in a GIS. As was mentioned in Chapter 5, given the huge choice of GIS software available, the particular choice of same is dependent upon the range of functionality required. It is the intention of this chapter to describe the functions (or operations) that a typical GIS may perform. Since the most expensive GIS programmes are capable of performing over 2 000 separate functions, and even an inexpensive GIS will perform hundreds of functions, then we can only give an indication of the most important ones here. These are set out under broad headings in Table 6.1. It should be stressed that not all of these headings are "hard and fast", and indeed there will be a considerable degree of overlap, or blurring, between GIS functionality. Thus different authors or different GIS programmes may classify functions, manipulations, analyses and ways of data management in very different ways, and terms such as "conversions" or "transformations" may be interchangeable and may feature under a number of the headings given in Table 6.1. Further details on GIS operations and functionality can be obtained from Burrough (1986), Aranoff (1989), Star and Estes (1990), Maguire et al (1991), Martin (1991), Bernhardsen (1992) and Environmental Systems Research Institute (1993), whilst details on the more theoretical aspects of spatial and data modelling and manipulations can be found in Preparata and Shamos (1986), Foley et al (1990), Laurini and Thompson (1992) and Bonham-Carter (1994).

Table 6.1 A Classification of GIS Functions

Data Pre-processing and Manipulation

(i) Data validation and editing, eg checking and correction.
(ii) Structure conversion, eg conversion from vector to raster.
(iii) Geometric conversion, eg map registration, scale changes, projection changes, map transformations, rotation.
(iv) Generalisation and classification, eg reclassifying data, aggregation or disaggregation, co-ordinate thinning.
(v) Integration, eg overlaying, combining map layers or edge matching.
(vi) Map enhancement, eg image enhancement, add title, scale, key, map symbolism, draping overlays.
(vii) Interpolation, e.g. kriging, spline functions, Thiessen polygons, plus centroid determination and extrapolation.
(viii) Buffer generation, eg calculating and defining corridors.

(ix) Data searching and retrieval, eg on points, lines or areas, on user defined themes or by using Boolean logic. Also browsing, querying and windowing.

Data Analysis

(i) Spatial analysis, eg connectivity, proximity, contiguity, intervisibility, digital terrain modelling.
(ii) Statistical analysis, eg histograms, correlation, measures of dispersion, frequency analysis.
(iii) Measurement, eg line length, area and volume calculations, distance and directions.

Data Display

(i) Graphical display, eg maps and graphs with symbols, labels or annotations.
(ii) Textual display, eg reports, tables.

Database Management

(i) Support and monitoring of multi-user access to the database.
(ii) Coping with systems failure.
(iii) Communication linkages with other systems.
(iv) Editing and up-dating of databases.
(v) Organising the database for efficient storage and retrieval.
(vi) Maintenance of database security and integrity.
(vii) Provision of a "data independent" view of the database.

6.2 Data Pre-processing and Manipulation

Under this heading we will consider a large number of functions which a GIS may be required to perform in order to get the digital mapped data into the desired format so as to obtain requisite map output or to confidently allow for any subsequent data analysis. Essentially, this means that the original digital data may need to be changed in some way, i.e. either by correcting it, updating it, refining it or by altering it in some desired way. Some of the pre-processing functions have already been described in section 4.5.3, and it is possible that many of the functions can be performed using other types of software, e.g. image processing packages. The capacity of a GIS to perform pre-processing means that the user has a huge opportunity to "interactively experiment" with the available data, thereby allowing for the appropriate data to be derived according to the task in hand. The efficiency in which individual GIS's perform manipulations will depend upon the particular algorithms which they use and the way in which the data is structured.

6.2.1 Data Validation and Editing

In essence this function represents the checking and revising of any data which has previously been captured, with the obvious aim being to minimise errors. In the case of digitised data, it is often possible and desirable to perform editing immediately following data capture, i.e. as a final stage in the digitising process, but it is important to note that many GIS software programmes allow for the detection and correction of digitising errors as a pre-processing function. Typical digitising errors are shown in Figure 6.1.

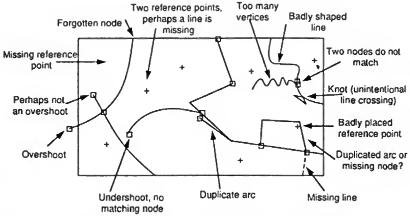


Figure 6.1 Typical Errors Which Might be Made Whilst Digitising (after Laurini and Thompson, 1992)

GIS software also contains programmes for verifying the correctness of all geometric, topological and attribute data, e.g. making certain that all graphical data is suitably defined, that attribute data does not exceed expected ranges and that impossible combinations of attributes do not occur. Data may be copied, deleted, moved, joined, altered, etc. Any of these data editing functions should be capable of being performed on both the graphical and the textual data. If data is not carefully verified, and errors remain, then manipulations of the data at a later processing stage will cause error propagation and multiplication, thereby invalidating, or at least making less useful, any final GIS output. Further details on the importance of data validation and error correction can be found in Burrough (1986), Goodchild and Gopal (1989), Dunn et al (1990), Chrisman (1991), Thapa and Bossler (1992) and Rybaczuk (1993).

6.2.2 Structure Conversion

In section 4.3 we showed why it was preferable to structure digital data in such a way that it required less storage space. For many manipulations it may also be preferable to convert data from a raster to vector structure, or vice versa. This is necessary since there are still no truly integrated GIS's which are able to handle both raster and vector data with equal ease. Figure 6.2 provides a useful conceptual summary of the necessary steps in both of these conversions. It is important to note that in the vector to raster conversion (rasterising) there will be an inevitable loss of accuracy, a factor which would be exacerbated both with increasing sinuosity of the lines and with increasing raster cell size. In the raster to vector conversion (vectorising) the GIS software programme performs a vectorising process which "threads" a line through groups of pixels using a special "thinning" algorithm. There will be a consequent need for topological information to be constructed and for individual features to be identified. These latter requirements can call for considerable operator intervention, but there are GIS functions which automatically compute new nodes and links and compile topology tables. Star and Estes (1990) explain in some detail the advantages of certain raster to vector data structure conversions, i.e. according to the type, and the proposed use for, the data being handled.

6.2.3 Geometric Conversion

When performing manipulations on mapped digital data, it is important that, if the data is to be merged in any way, then it should all conform to the same geometric reference system. Latitude and longitude co-ordinates are frequently used in small scale mapping, although the most frequently used co-ordinate system in GIS is the Universal Transverse Mercator (UTM) system (Figure 6.3). Nearly all GIS software allows for the possibility of converting the map referencing system used to a wide range of possible map projections or from one co-ordinate system to another. Such processes are sometimes called transformations or rectification. Transformations are based on the mathematical relationships that exist between the various map projections, i.e. relative to angles, areas, direction and distances. A more basic type of geometric conversion is called registration. This is simply changing one mapped view to line up with another, i.e. irrespective of any referencing system.

Figure 6.4 illustrates some further geometric conversions. Scale changes are easily accommodated via a simple multiplier function and maps can easily be rotated to particular orientations. A more complex function which most GIS's can achieve is the correction for distortions (rectification). These distortions may occur in the original source data for a number of reasons, e.g.

(a) Aerial photographs or RS satellite images have varying scales due to platform tilt and the curvature of the Earth.
(b) The angle of view or relief differences also cause variations in scale.
(c) Photographs or maps variably shrink with age.
(d) Maps on paper can easily suffer from stretching.
(e) Distortions in the optic systems being used.

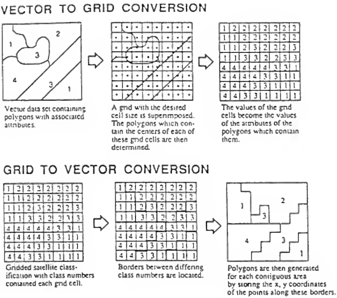


Figure 6.2 Summary of Vector to Raster and Raster to Vector Structure Conversion (from Robinson Barker, 1988)

Distortions are manipulated by "rubber sheeting" methods, i.e. by treating the distorted image as an elastic sheet which can be stretched or compressed until it exactly fits a selected base mapon which there are positively identifiable ground control points.

6.2.4 Generalisation and Classification

Under this general heading a large number of manipulations can be performed, all of which are designed to change the data in some way such that it can be more easily used for a particular purpose, e.g.

(a) Adding to data, or deleting undesirable data.
(b) Aggregating or disaggregating numerical or attribute data.
(c) Classifying or reclassifying data into user defined, or GIS suggested, classifications. This usually involves deciding upon attribute value classes or changes to existing classes.
(d) Using data reduction algorithms to generalise or smooth linear data, e.g. to thin out co-

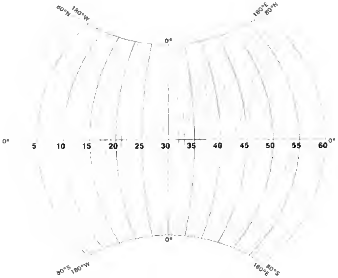


Figure 6.3 **The Universal Transverse Mercator (UTM) Zones**

ordinates in digitised lines (in order to greatly reduce the amount of data storage). Figure 6.5 illustrates how generalisation can be applied to a well known map outline.

(e) Lines can be deleted or "dissolved" in order to simplify mapped surfaces.

(f) New attributes can be assigned to spatial points, lines or polygons.

(g) Annotations can be added to maps using labels, text, legends or cartographic symbols.

6.2.5 Integrations

These manipulations involve the creation of new or revised mapped surfaces by (in one way or another) joining two or more previously defined maps. Perhaps the most frequently performed manipulation under this heading is the merging by overlaying of two or more mapped layers, i.e. any number of raster or vector map layers can be progressively added or subtracted to produce a desired map. Existing data on a single theme can be merged, e.g. a water qualitative map could be progressively built up by merging maps of perhaps water temperature, pH, dissolved oxygen, salinity, etc. By merging these layers a new map would be created which consisted of numerous polygons, each of which may have a different combination of water qualitative factors. The overlaying of maps can give rise to major problems. For instance, it is

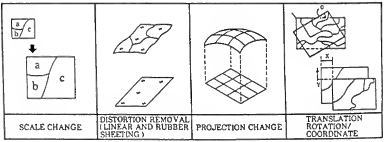


Figure 6.4 Some Geometric Conversions Which a GIS May Perform (after Dangermond, 1983)

likely that many new polygons will be created, some of whose boundaries should correspond between the two maps being overlayed. Invariably the original data sources will be different, or the digitising will be inaccurate, and the new map will exhibit numerous so-called "slivers", i.e. polygons arising from a poor match between boundaries or other lines (Figure 6.6). Here the overlaying of map a) on to map b) created map c) with its numerous slivers. There are now "intelligent" algorithms in some GIS's which can automatically counteract these slivers, i.e. as in Figure 6.6 (d). Other algorithms will also be needed to establish new topology and new attribute tables. It can be seen that overlay procedures are quite complex and they may take up a lot of computing time.

Frequently it will be necessary to form a new map by accurately joining two mapped sheets (or many contiguous map sheets) along their edges, i.e. by edge matching, so that all linear and area features exactly coincide. A seamless dataset is then produced. When merging or integrating maps it will also be necessary to take into account possible variations in the data structure and format between any two maps, plus the ways that have been used to assign labels or to identify objects. So inevitably, integration must be performed with a great deal of consideration as to the integrity and make-up of the data being used.

6.2.6 Map Enhancement

These GIS functions simply consist of a series of operations which allow for the cartographic refinement of the finished map, i.e. at the manipulation stage factors concerned with map presentation can be improved. This may include adding a suitable border to the map, varying the width of mapped lines, altering chosen colours, varying the fonts or font size, altering the layout of the map or the position of textual features such as the key or title. If a 3-D image has been created this might be the stage at which a land use categorisation could be draped over the image.

(a)

(b)

Figure 6.5 Illustration to Show How a Map Outline Can be Generalised

6.2.7 Interpolation

This is the procedure for estimating the values for any continuous (rather than discrete) "properties" at unsampled sites along a line or within an area. This must be based on existing point observation data within the area (or along the line), which themselves should have been derived using valid measuring and sampling techniques. Figure 6.7 shows how isolines (lines joining places of equal value) have been interpolated from known values at several points. The problem in interpolation is choosing the model which is best able to produce correct interpolations, i.e. a model which suits the data array and the way in which actual variability occurs. Many simple GIS interpolation procedures rely on the use of various weighting functions, i.e. this allows for the logical fact that near points used in an interpolation should count for more than distant points. There are more complex interpolation models which cover

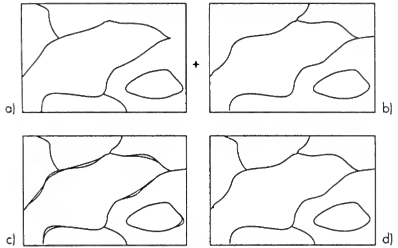


Figure 6.6 Illustration Showing How Overlaying Techniques Can Lead to Poor Integration (from Bernhardsen, 1992)

2-D arrays of data points e.g. Thiessen polygons, the use of kriging or Fourier series, or models which can be applied to interpolating linear pathways, e.g. the fitting of spline functions. A special case of interpolation is centroid determination. In this function the GIS is able to calculate the co-ordinate location of the centre of a polygon. Extrapolation is simply the using of interpolation techniques to extend calculated trends beyond the area of specific study or interest, or beyond the range of the data held. Burrough (1986) and Martin (1991) provide comprehensive coverages on interpolation and Laurini and Thompson (1992) provide a detailed description of the various models for interpolation.

6.2.8 Buffer Generation

Since a fundamental concern of GIS is with spatial distances, it is frequently useful to determine what are known as buffer zones (zones of equal distance) around a point or an area, or along a line. Figure 6.8 shows how simple buffer zones are created around a point, line and polygon in the raster structure. Buffers may be generated by the GIS at any preset distance and they might represent features such a maximum market range around a town, a legal exclusion zone, a zone of noise disturbance or a zone in which some economic rights exist. Buffer zones are clearly very useful in the compilation of many geographic models, though in reality their use may be restricted, mainly to isotropic surfaces.

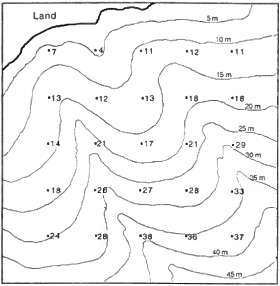


Figure 6.7 A Simple Example to Show Interpolated Isolines

6.2.9 Data Searching (Query) and Retrieval

For discussion purposes the two processes of searching (querying) and retrieving can be viewed together, i.e. as a single process. In order that a GIS can perform any analytical procedure, it is essential that the software is able to selectively search and retrieve requisite data by as many criteria as possible. These criteria will include mapped data (lines, points and polygons) as well as attribute, numeric or textual data. The searching for data is performed using a dedicated Standard Query Language (SQL) and any search may be confined to a certain mapped area or to a specific theme. It is further possible to selectively retrieve data in various ways. For instance data can be classified by any theme, region or class. It is common to retrieve data using the rules of Boolean logic. Here the simple operators of "AND", "OR", "XOR" or "NOT" are stated to show which sort of conditions need to be met before the data is retrieved. Commands for search and retrieval using Boolean logic can be relatively complex. So, for instance, the GIS could be instructed to "find all the marine areas having a mean water temperature of >20C, in combination with a depth of <50 metres, which are situated in the waters of both country "x" and "y" and in which quotas do not yet operate". Complex requests like this can involve any parameters for which the data is held.

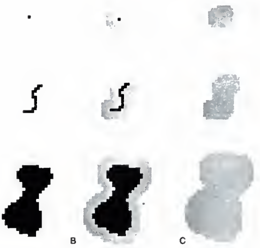


Figure 6.8 Buffers Around a Point, Line and Polygon

6.3 Data Analysis

It is the incorporation of analytical functionality which arguably distinguishes a true GIS from other forms of mapping packages. Recently there has been criticism that many GIS packages have lacked a sufficient range of analytical functions, but nowadays this would seem to be unfair in the sense that most packages have at least a limited range of such functions. Also, it is now usually a simple matter to link a GIS package to a specialist analytical software programme in which the analysis is carried out before reverting back to the GIS software for mapping. Additionally, it is not usually worth the time and financial effort involved for a software house to integrate lots of analytical functions, i.e. since most of these are only required for research purposes.

The analytical functions which most GIS software provides operate on both the spatial or the attribute data (or a combination of these). Most of the following analyses can be performed on both vector or raster structured data, though inevitably one or other of these is more efficient depending on the actual analysis being performed. Some authors have reviewed analytical capacities under headings which correspond to the types of data, i.e. point analysis, polygon analysis and linear analysis or vector analysis and raster analysis, though we have chosen to discuss the techniques under the headings of spatial, statistical and measurement analyses. Figure

6.9 shows examples of raster analytical techniques. Laurini and Thompson (1992) or Bonham-Carter (1994) provide a detailed theoretical background on how the various analyses are performed.

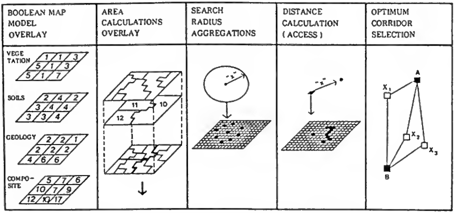


Figure 6.9 Some Raster Based Analytical Techniques (from Dangermond, 1983)

6.3.1 Spatial Analysis

In Table 6.1 we gave examples of some of the important types of spatial analysis which may be performed. Here we can briefly expand upon these.

(a) Connectivity (or network) analysis is useful for determining how well connected any particular site is via any method of communications. Thus a connectivity index can be worked out which shows, for example, for all towns (nodes) in any selected area, the relative number of road or other communications or pipeline connections (links) which exist between each town and all the other towns in that area. Connectivity can also be conceived in terms of distance, cost or time, and it is useful in optimising route allocations. Figure 6.10 illustrates how connectivity is recorded for a simple set of links and nodes.

(b) Proximity and contiguity analyses are respectively simply methods of determining and indicating measures of distance between locations, or of showing a location's degree of adjacency to neighbouring locations. Figure 6.11 shows how contiguity is recorded for polygons in a small area. The creation of a buffer zone is an example of a proximity operation.

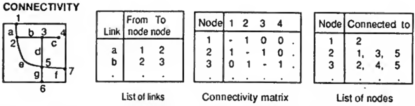


Figure 6.10 Method of Compiling a Connectivity Matrix (after Laurini and Thompson, 1992)

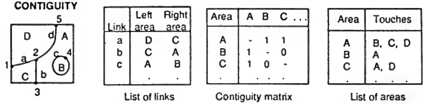


Figure 6.11 Method of Compiling a Contiguity Matrix (after Laurini and Thompson, 1992)

(c) Intervisibility defines, from map evidence, whether or not it is possible to have a direct line of sight between any two points on the map. Thus a calculation is made, bearing in mind the existence of high ground as shown by contours, whether or not hills or other high ground would obscure the line of vision.

(d) Digital terrain modelling is the process whereby it is possible, using digitised height data, to build a 3-D model of any desired area. These models amy also be called 2.5-D since they only show surface heights and not true volumetric data. From the marine point of view it would be equally possible to use bathymetric data to construct visual models showing the physical appearance of selected areas of the sea floor.

(e) Location optimisation is now being widely used as a GIS based method which allows for the selection of optimum locations for the siting of any activity. This analysis is usually used by larger commercial companies when seeking, for instance, sites for new retailing outlets or for centralised distribution points. In these cases various spatially variable economic and social indicators, such as the social class structure of an area and the population density, would need to held in a digital geo-referenced form. Similar analyses are also used by the forestry and agricultural sectors in seeking to optimise their operations, though here physical rather than economic criteria might be more important.

(f) Trend surface analysis is a method for establishing whether a generalised spatial surface exists, i.e. one which may be obscured by a mass of detail in the real world. For instance, in any one country there may be an overall "wealth" surface which trends perhaps from east to west but which could well be obscured by numerous pockets of prosperity or poverty. From the marine viewpoint, it is quite likely that trend surfaces would exist with regard to the distribution of particular species, i.e. such that they would gradually decline outwards from a biologically optimum area but in an irregular, and thus perhaps obscured, way. The fitting of a trend surface therefore becomes a useful way of identifying spatial anomalies - points or areas which are above or below the general trend.

6.3.2 Statistical Analysis

As with the spatial analyses, there are a huge range of statistical functions which any individual GIS might be able to perform. Since many of these functions are not particular to GIS, i.e. they are commonly performed by statistical packages, or spreadsheet or database packages, then we need not elaborate on them here, except to mention that it is possible to link many existing statistical packages with GIS software as a means of executing statistical analyses. These include simple descriptive statistics showing measures of centrality, frequency analyses or measures of dispersion, plus more complex correlations and multi-variate analyses. Many GIS's are now capable of performing some complex spatial statistical analyses such as spatial autocorrelation and nearest neighbour analysis. Spatial autocorrelation is used to provide a measure of contiguity between areas, e.g. Figure 6.12 shows the theoretical range of possible autocorrelations. If a marine species were shown to be distributed in any of these ways, then we might need to seek explanations. Nearest neighbour analysis provides a relative measure of the dispersion of points in a given area, i.e. they may tend towards clustering, randomness or a uniform spread. There is now some recognition of the importance of geostatistical capabilities as a functional tool within GIS's (Thomas, 1991).

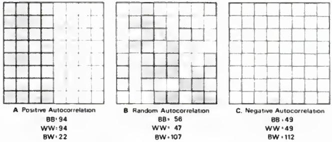


Figure 6.12 The Possible Range of Spatial Autocorrelation

6.3.3 Measurement

Under this heading, a GIS will be capable of performing a large number of operations on one or more data layers. Measurement will vary from simple counts (enumeration), to measuring linear or curvilinear distances, to calculating areas, perimeters or volumes or to recording directional or angular measurements. The derived measurements can then form the bases of further work using the GIS software, e.g. tabular or graphical displays. Clearly certain data structures will lend themselves more easily to different types of measurement. Thus it will be a simple task to compute area if a raster format is used, whilst distance measurements can be more accurate using vector data, i.e. if only because the central point of a pixel (in the raster structure), from where distances are measured, may not be the true starting point.

6.4 Data Display

A major anticipated use for any GIS will be to display the data, i.e. the display capacity will represent the output from the system as presented initially on the VDU. A fundamental usefulness of the concept of GIS is that it can display output at any stage in the processing of the data. So the GIS provides the facility for maps to be incrementally built up, with desired modifications being possible at any stage. Modifications might be in terms of changes to the data inputs to the map, or in terms of the visual representation of the map. So the GIS user can control, review or experiment at any stage in order to achieve a meaningful final output. All good GIS software will have a range of graphic display features to control factors such as label size, fonts, colour or shading ranges, line widths, symbolism, map feature positions, etc. And the format of the display is not confined to maps - it may be in graphical, tabular or textual forms. The early 1990's has witnessed a huge emphasis in the GIS field on the perceptual science of "visualization" - how we look at maps, what information is being conveyed, how people may each view the same mapped scene differently, different ways of communicating information, etc. For those interested further in visualization we would recommend Earnshaw and Wiseman (1992), Bonham-Carter (1994) or Hearnshaw and Unwin (1994).

The data display itself can be temporary or permanent. Temporary display is that which is captured on the VDU. It is the functional user interface in that the VDU shows the results of any commands which have been given via the keyboard, and interactive experimentation can then take place at no cost, at great speed and in an almost infinite variety of ways. Only when the user is satisfied with any temporary screen view need permanent output be obtained. Permanent output is usually by means of hardcopy display, as obtained by the use of any of the variety of devices described in Section 5.2.4, though it may also be permanently saved to an internal hard disk, or to some form of transferable disk or tape, or it may be sent to an alternative location via networking facilities. Hardcopy display is usually output to paper or film and may be in black and white or multi-coloured. The display will vary in quality as a function of the GIS capability, the detail of the data, the scale of mapping, the quality of paper, the use of vector or raster structuring or, most importantly, with the quality of the output hardware being used and the printing resolution (in dpi) to which it is set. The best quality digital output is now superior to that which can be achieved by manual methods.

In the near future it is likely that GIS output, and indeed its full range of functionality, will be capable of display and/or use aboard suitably equipped fisheries vessels. Many vessels now have quite sophisticated navigation systems which utilize electronic charts in conjunction with radar and plotting facilities. These can display a variety of static information covering bathymetry, navigational features, land masses, restrictive areas, etc, plus the tracks of moving vessels. It will be a simple progression to extend this functionality so that other desirable layers will be capable of being integrated and displayed in an interactive mode, i.e. such that the vessel has on-board ability to perform a range of required GIS functions.

6.5 Database Management

Space prohibits a detailed look at databases or database management systems (DBMS), but further details relating DBMS to GIS can be found in Martin (1986), Austin (1989), Maguire (1989), Dale (1990), Date (1990), Batty (1992), Howells (1993) and Laurini (1994), and many other texts are specifically written on this topic. An introduction to GIS databases was given in sections 4.2 and 4.3, and we remind readers here that a database may be defined as a large collection of related data which has been structured in an ordered way but which is independent of any particular application. For GIS purposes this collection of data may be stored externally in digital form in a purpose created computer software database package, e.g. Oracle or dBASE, or internally in a database which forms part of the GIS software. Attribute data is frequently stored externally whilst the geographic data are more commonly stored within the GIS software.

Distributed databases are also commonly used in GIS and becoming more so. In this case the data may be held in disparate sources within or outside an organisation. Obviously, if a GIS has access to such databases then a vast range of extra data becomes available to the system. In the fisheries context, it is easy to envisage that a GIS could offer greater functionality if it could have direct access to oceanographic, meteorological and perhaps environmental databases, all of which were likely to be situated separately from the fisheries GIS. Laurini (1994) provides a useful overview of distributed databases, plus the many problems to be overcome before their use can become more universal. Anon (1993b) provides detailed information on how a major database, the Regional Maritime Database (BDRM), is being built to cover the marine areas along the West African coastline. This database will be capable of being accessed by any or all of the 10 participating countries, and all information is being specifically geo-referenced so that GIS functionality can be ensured.

6.5.1 Database Management Systems (DBMS)

A DBMS is a computer programme for creating, maintaining and accessing digital databases. There are a large number of commercial packages available for doing this. The DBMS provides the essential link between the GIS software, external data sources or graphics enhancing packages and any operations which the user might wish to perform. DBMS can work with different data types such as characters, numerals or dates; they have languages for describing or manipulating the data or for querying the database for particular pieces of information; they

provide programming tools and they have particular file structures. Table 6.2 lists the principal features which a good DBMS should be capable of performing.

Table 6.2 The Main Features Required of a Database Management System

* To create data bases which are in a carefully structured and consistently logical format.
* To create new data bases.
* To extract data from the database in a variety of ways.
* To persistently and constantly execute any commands.
* To display data as required.
* To edit data in any requisite way.
* To sort data.
* To allow for the transfer of data between various software packages.
* To protect data against loss, unauthorised entry, copying and destruction.
* To protect against any inconsistencies which may result from multiple simultaneous use of the database.
* To be independent of particular hardware needs.

The reasons for having a DBMS are fairly basic. Thus firstly, it is obvious that the data needs to be maintained in the sense of being kept up-to-date, correct, properly ordered, properly structured, etc. It also has to be managed so that it is properly understood, and that it is available how, when, where and to whom it is required. Storage structures must be constantly monitored so as to minimise storage space and to maximise searching efficiency. And since most databases are constantly growing, new fields might need adding or indeed old fields might need deleting. A database manager is usually assigned who can not only manage all of the above, but who can also regulate access to the database, cope with systems failures when they occurred and who is able to link databases with external databases if required. He or she may also be required to cope with the legal sides of data management, i.e. making certain that inaccurate decisions are unlikely to be made as a consequence of using his data, and making sure that copyright infringements are not made.

For a DBMS to be most effective it is important that the data is stored in an orderly way. There are basically four types of DBMS structural/storage methods: - hierarchical, networked, relational and object oriented.

(a) Hierarchical. In the hierarchical model each record can have a number of links to lower "levels", but only one link to a higher level. The highest link is the "root", lower levels are called "children" and levels above are called "parents". Figure 6.13 shows a typical hierarchical data model for a hypothetical mapped area. Hierarchical data structures are easy to understand and to update or expand and they are useful where up and down searching is required, but they are not very good in circumstances where horizontal searching is carried out, i.e. where it might be necessary to locate all records which are at one level, since there are no connections at the same level.

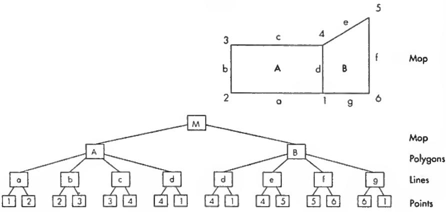


Figure 6.13 A Hierarchical Database Structure Based on a Simple Map (after Bernhardsen, 1992)

(b) Networked. This is similar to the hierarchical data model but here it is possible to have more than one parent, and thus many-to-many relationships can be found. Figure 6.14 shows that a networked database structure can be analogous to a communications network where there may be many linkages between any combinations of centres. This type of data structure makes good use of the available data, with rapid connections being possible, but it is difficult to create and maintain. Both hierarchical and networked structures are now seldom used in GIS's.

(c) Relational. Here data is organised in a series of tables, each of which contains one type of record. The rows of the tables correspond to records and the columns to fields of the records. Each table in the database will be linked by a common field, otherwise called a unique identifier (or a key attribute). Data is extracted from the database by defining the relationship which is appropriate to the query being asked. This could well involve the use of relational algorithms in order to construct new tables if required. Figure 6.15 shows an example of the use of a relational database as it might apply in a fisheries situation.

Relational databases are very flexible and are easy to establish, use and maintain. Almost any relationship is possible to work out by the use of Boolean logic and mathematical operations, and additional data can easily be added to the database. The main drawback lies in the fact that searches can be very time consuming, i.e. given the calculations and other specifications involved and the huge numbers of tables which might be needed. The Standard Query Language (SQL) has been developed as the standard language for use with the relational DBMS, and this kind of database is the one most frequently used by GIS's. Floen et al (1993) describe in detail how a relational database has been set up in the Institute of Marine Research in Bergen, Norway, to access, query and manipulate all of their data holdings.

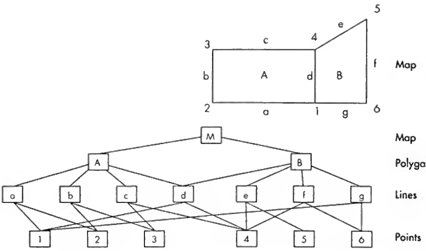


Figure 6.14 A Networked Database Structure Based on a Simple Map (after Bernhardsen, 1992)

(d) Object Oriented. This is a new type of DBMS which is slowly being developed, on a world-wide basis, mainly under the guidance of the Object Management Group (Leach, 1993). This group intends to make object oriented DBMS the norm for the future by ensuring that they are extremely efficient and that there is a world-wide common framework for their development so that they can work across all environments, on all hardware platforms and under any operating system. These databases take a sophisticated view of geographical entities and as such object oriented DBMS are conceptually difficult to explain and to understand. Basically all entities are considered as having the three fundamental concepts of: object, class and inheritance. For instance, geographic objects might be "road", "port", "sea", etc. Each object can then in turn have a class such as "Secondary (road)", "Fishing (port)" or "Shallow (sea)", and they may also have sub-classes. Each object can also be defined as having certain properties, e.g. a fishing vessel may have an owner, a value, a size, etc., and each object may have certain functions (operations or methods) which can be performed on them, e.g. select, measure, locate, modify or draw. Inheritance means that when a class is added to an object, then all aspects of "class" can potentially be included in the new description, e.g. all aspects pertaining to "Fishing" can potentially be linked to the class of "Fishing port". For those seeking a more detailed explanation of object-oriented DBMS, then or Laurini and Thompson (1992) or Cooper (1993) give reasonably easy definitions.

TABLE 1

County	No. of Fishing Vessels
Kent	300
Essex	250
Sussex	150
Hampshire	300

TABLE 2

Post Code	No. of Fishing Trips/Year
CT	7000
HL	3500
FM	2100
BS	5500

TABLE 3

Post Code	County	Percent
CT	Kent	80
CT	Essex	20
HL	Kent	20
HL	Sussex	70
HL	Hampshire	10
FM	Sussex	30
FM	Hampshire	70
BS	Hampshire	100

TABLE 4

Number of Fishing Trips Per Vessel

CT = 7000 / [(300 * 0.80) + (250 * 0.20)] = 24.1
HL = 3500 / [(300 * 0.20) + (150 * 0.70) + (300 * 0.10)] = 17.9
FM = 2100 / [(150 * 0.30) + (300 8 0.70)] = 8.2
BS = 5500 / [(300 8 1.00)] = 18 3

Figure 6.15 The Use of a Relational Database for Integrating Fishing Vessels and Home Ports

Object oriented databases provide a vehicle for representing data in a form similar to that of the real world. The fact that data is realistically modelled makes user interaction easy and the DBMS is also easy to update and therefore to maintain. There are currently many problems which must be overcome with these databases before they become widely adopted (Batty, 1992), the main one being the lack of a standard object-oriented query language (Kufoniyi, 1995). However, whilst in the past relational databases have been most favoured by GIS users, the move is now towards the benefits of object orientation and this is likely to continue.

CHAPTER 7 - POTENTIAL USES FOR A MARINE FISHERIES RESOURCE GIS

7.1 Introduction

The purpose of this chapter is to conceive of how a marine fisheries resource GIS might best be set up in terms of its varying potential to help with fisheries management. As was indicated in Chapter 1, marine fisheries is both a subject area which is extremely broad, and an activity which is carried out over a significant proportion of the Earth's surface by a vast number of people and groups. Comparative freedom of access to the marine resource base, coupled with fragmentation of the fishing communities, has meant that in the past coordinated fisheries management strategies have seldom been implemented. During this century there have emerged various attempts at fisheries management, first by biologists and later by economists, sociologists and then environmentalists. But for too long these attempts have been pursued in a more or less mono-disciplinary way. Continued over-exploitation and declining fish stocks have shown this to be the case, and the situation has now been reached whereby, if marine areas are to continue to yield fish and other biomass resources, then better, integrated management strategies are imperative.

In Chapter 1 it was also made clear that a major problem for fisheries was that it was a multi-faceted discipline, operating essentially in a spatially extensive and spatially variable environment. In the following chapters we demonstrated that GIS is a tool which has the necessary requirements and functionality to allow for spatial management across multi-disciplinary subject fields. For any GIS to achieve optimum operative capability then, as was shown in Chapter 6, it is clear that the data which is entered into the system needs to be managed. In this chapter we intend to give suggestions and examples of how this data management can best be achieved.

7.2 Some Methodological Problems to be Considered in the Construction of Marine Fisheries Databases

Before looking at the potential individual database areas into which a marine fisheries GIS might be subdivided, it is relevant to outline some of the general methodological problems which are likely to be encountered across all or some of the database areas. Under this heading we are referring not to specifically GIS based operating or functional problems, but to those considerations which might prove difficult to solve when setting up databases for the various facets of marine fisheries.

7.2.1 Operating in a 3-D Environment

The vast majority of entities which are mapped are distributed in 2-D space. Although this mapping may give rise to considerations of scale, symbolism, classification, generalisation, etc,

relatively speaking it causes comparatively few problems. Some entities may need mapping, or displaying, in 2.5-D, i.e. where altitudinal differences are shown by various means on a 2-D surface. There are ways of easily accomplishing this either by showing the height dimension (or depth dimensions for the oceans or seas) using contours, hachures and various shadings, or by the use of various "three" dimensional, elevational models. However, the problem for those wishing to map fish biomass distributions is that they nearly all occur in genuine 3-D space (the exceptions are, of course, wholly demersal or bottom living species).

From a practical viewpoint the implication of this is that the fisheries management team, in conjunction with those operating the GIS and those setting up data collection systems, have to make decisions concerning how best to portray species distributions in this 3-D space and how to set up databases which record in three dimensions. Clearly one answer is to simply ignore the third dimension. This would mean that any map drawn would be a spatial representation which ignored the vertical distribution of the species (or of water qualitative parameters). For many mapping instances this may not be a problem, and indeed, in many mapping scenarios it is likely that there is insufficient data available to allow for mapping in any other way. An alternative answer is to map distributions by suitable vertical depth class categories, i.e. with there being as many maps for any one area as there were depth class categories. The actual categories used would vary with the number of class divisions, the purposes of mapping, the depth of the water and likely species or water qualitative distributions. This mapping would involve the procurement of quite detailed distributional data, often via acoustic methods. Data sets would be very large per unit of surface area.

Work is now in progress on sophisticated modelling and mapping methods whereby, for any desired mapping plane along any axis, it is possible to take a "slice" through a representation of any plotted 3-D distribution so as to show the distribution in 2-D across the desired plane. Figure 7.1 shows a hypothetical example of a 3-D "cube" of marine space with a "slice" taken through the latitudinal axis. The slice shows fish biomass density variations given the specific combinations of latitude, longitude and water depth. Although this methodology has yet to be incorporated into present GIS's, it will in the future allow for some quite sophisticated 3-D maps to be drawn, especially in instances at a larger scale whereby particular vertical distributions were comparatively stable over time and space, e.g. perhaps generalised seasonal thermoclinal models. Manley and Tallet (1990) have shown examples of experimental work which shows how optimal visualization is being achieved using 3-D GIS images of factors such as salinity and water temperature variations. There are also other initiatives underway which are aiming to develop genuine 3-D GIS's (Raper, 1989; Mason et al, 1992; O'Conaill et al, 1992; Li and Saxena, 1993; Hack and Sides, 1994; Houlding, 1994), but it may be some time before these are available for use in typical marine fisheries applications. The eventual decision on how to map in a 3-D environment should be made according to the purposes of the mapping and thus of the final data output required. Clearly there is no right or wrong way. The decision will be influenced by the type of source data held, the costs of getting primary data which is valid in 3-D space, the scale or spatial extent of the mapping and perhaps a cost/benefit analysis between alternative ways of mapping.

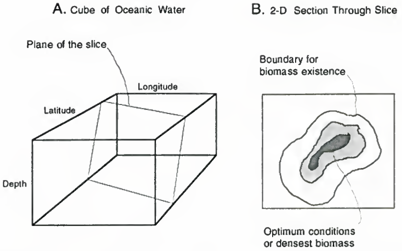


Figure 7.1 A 3-D Hypothetical Cube of Oceanic Water With a Slice to Show Fish Biomass Variations

7.2.2 Mapping in a Mobile and/or "Fuzzy" Environment

The vast majority of maps produced are spatial representations of the distribution of static objects or areas in the terrestrial environment. In this case it is easy to locate the entities in a relatively exact location vis a vis other entities. However, there are increasingly attempts being made to map objects which are non-static (e.g. Miller, 1994). This mapping may involve various types of representation such as flow lines, which show volumetric amounts of movement along certain corridors, e.g. the number of bus movements along various routes per a 24 hour time period, or perhaps mapped biological distributions of various faunal species. Although many of these latter maps can look successful, the map user will need to look with care at exactly what the map is purporting to show. Thus they might be showing the maximum extent of a species, areas where the species have been recorded within a certain time period, areas where the species have ever been recorded or areas where a species most commonly occurs. For the fisheries manager, there is the added mapping complexity in that not only do the species themselves show a high time/space variability, but so does their environment, i.e. the water quality may change, and this is frequently the causal factor for species distributional change.

This introduces the additional and related problem of actually defining boundaries in the marine or coastal environment, i.e. how, in this constantly changing milieu, is it possible to draw clear boundaries around zones or areas having relatively non-homogeneous properties? (e.g. imagine

the difficulties in drawing boundaries along a river estuary between saline, brackish and fresh water). Thus marine or coastal entities tend to have fuzzy or transitory boundaries which require methods of representation which, strictly speaking, can take this uncertainty into account. At the present state of GIS development, this is impossible, although progress is being made towards dynamic modelling which should result in measures towards solving these problems.

However, there are several ways of overcoming these various mapping problems. As alluded to above, mapping can show extreme, average or seasonal distributions, and for some types of mapping it might even be necessary to show diurnal distributions. The overall success of mapping which allows for the mobility of both species and their environment will depend on factors such as the importance of the mapping, the accuracy required, the scale of the area being mapped, the frequency of mapping and the relative amount of movement of the species or the water qualitative factor. Again, the fisheries management team will need to discuss exact requirements in terms of the task being undertaken.

7.2.3 The Type, and the Unit Area, of Mapping

We have previously mentioned (section 4.2.1) that all mapping entities may be thought of in terms of points, lines and areas, and the fisheries manager will be required to map examples of each of these in any GIS exercise. Static point features, linear features and all spatially extensive areas will be comparatively easy to map since their position and extent is easily determined. However, mobile point features (and sometimes other features) are not so conducive to normal mapping, and so they are frequently mapped as grouped quantitative variables. According to the purposes of mapping, to the numeric scale of measurement used, and the way in which the data has been gathered, quantitative variables may be mapped in various ways. Figure 7.2 shows three main methods which are commonly used, though there are many variates of these. Again, depending on the purpose of mapping, there is no right or wrong method to use.

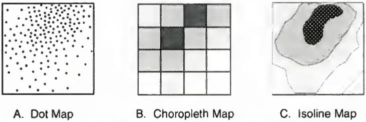


Figure 7.2 The Three Main Ways of Mapping Variable Quantities

From a practical viewpoint, in a GIS the fisheries manager would most frequently use either isoline or cellular mapping techniques. Where variables change slowly over a spatial continuum, such as water quality changes, then isoline maps can be reliably used so long as the source data is accurate enough and sufficient point samples are available. Although this method could also

be used for mapping perhaps fish densities, it would seldom be advisable because it is difficult to provide any guidance as to the statistical validity of the map. For this reason density mapping by unit cells is the best method. However, in the use of unit cells there is the problem of cell size to be considered. It is impossible to advise precisely on this since there are many factors that need considering, the most obvious of which are the total size of the marine area being mapped, and the density of species sampling data which is either held or planned. We would advise on the establishing of a nested hierarchy of cells to cover the whole marine area. Though this is discussed in Meaden (1994) we show here (Figure 7.3) how this might be represented.

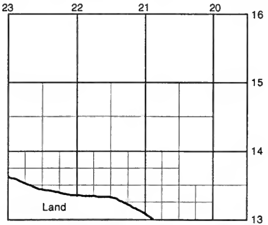


Figure 7.3 A Possible Means of Dividing a Marine Area for Mapping by Using a Nested Hierarchy of Cells

The choice of square cells relates to their usefulness in nesting, to the fact that simple algorithms exist which can provide a measure of the statistical significance of any survey data obtained, and to the fact that other raster type data is gathered in this way, e.g. RS data. Additionally, data held in cell units is structured in a format which will be advantageous to any raster based GIS software, and the geo-referencing of this data will be simple. However, for some aspects of a potential marine fisheries GIS, square cells may not be the optimum shape. For instance, if the concern is with modelling (simulating) the movement of marine organisms from a given starting point then, although any one square cell has eight surrounding cells, it is far more likely that the movement will be into one of the four adjoining side cells than into one of the four adjoining corner cells. Since this would clearly be unfair, then hexagonal shaped cells have been sometimes used, being a shape which also tessellates (Taylor and Ullman, 1993). Obviously a suitable geo-referencing system would need to be devised for the use of hexagonal tiling.

7.2.4 The Mapping of Statistical Variance

To obtain data on species existence and likely species quantities, various data sampling methods have been traditionally used. Although the data obtained is obviously useful, it is clear that in the vast 3-D space of the open sea, then there will be the likelihood of a huge margin for error, i.e. since the survey can only gather samples from a very small fraction of the total space. The margin for error will potentially be less for demersal species, who mainly occupy 2.5-D space (2.5-D indicates a surface link), than for pelagic species who may occupy much of any 3-D space. Differences in the behaviour of certain stocks and their rate of mobility is also important, e.g. the sampling of stocks which exhibit a high shoaling density will call for different sampling strategies than those where members of a stock are ubiquitously distributed, and this sampling logic also applies to species which are more migratory than others. The implication of this is that, when it comes to any mapping of the species surveyed, the data used has the potential to contain a large margin of error, i.e. the statistical variance in grouped sample data is likely to be very high. In many cases therefore, confidence in the validity of the data will not be high. The extent to which this is true will depend on the accuracy and frequency of surveys, plus the survey methods used, though it might also depend upon the dispositional habits of the particular species being mapped. Meaden (1995) has suggested that, where relevant, GIS output can incorporate maps which give an indication of variance. Thus, Figure 7.4 shows an example whereby hypothetical estimations of fish biomass and of variance in the survey data is shown simultaneously.

From the GIS viewpoint, this lack of confidence in the data and the high likelihood of error, is a cause for concern. This lies mainly in the fact that, if the data is to be used as the basis for any manipulations, then errors are going to be multiplied. So, for instance, if the fisheries manager is hoping to maintain a record of fish stocks in a particular marine zone, via the use of GIS, then manipulations would need to be made which involved adding recruitment estimates to existing surveyed stocks and then subtracting the total of fish catches and/or fish mortalities and migration. Notice that data on recruitment, mortality and migration might also be subject to large statistical variance. So, given the present state of fisheries surveys and GIS functionality, then it must be recognised that output data (map or tabular) should in many cases be treated with some caution. However, this is an area where there are likely to be rapid future improvements, especially with the widespread introduction of acoustic methods of stock assessment, and with the likely advent of realistic models to show marine species quantity and distribution both temporally and in 3-D space. In fact, we would contend that the use of GIS is likely to help provide evidence that, for certain species at least, their spatial disposition is likely to follow certain quite well defined patterns. Readers interested in the problem of spatial variance associated with fish stock distributions should consult Smith (1990), Foote and Stefansson (1993), Gunderson (1993) or Petitgas (1993).

7.2.5 Spatial and Temporal Scale Problems

It has already been indicated that, since most marine stocks are to a greater or lesser degree, mobile then any map showing their distribution is going to have a poor temporal resolution, i.e.

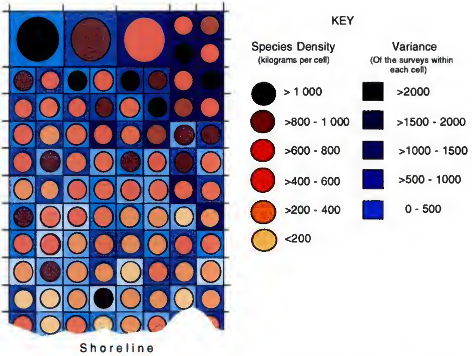


Figure 7.4 Simulated GIS Output to Show the Incorporation of Variance Estimates Into a Fish Biomass Survey Map

the map is rapidly going to become dated, and it could only be "accurate" if it was purporting to show the approximate species distribution for a very particular time period. Other factors relative to marine fisheries and resources are also going to be variable over time, e.g. the distribution of fishing effort, the extent of market zones, water quality or quotas per unit area. The temporal scale used in GIS mapping has to be a function of many variables most of which will relate to the purposes of the mapping, the temporally variable data available and probably a perceived cost/benefit decision by the fisheries manager.

Another important decision for which there are no hard and fast rules is that concerning the spatial scale(s) of any mapping. The scale decided upon will vary as a function of the purposes of the management task, the detail required, the input efforts available, the relative mobility of a species or the area that it occupies, and the extent of the marine area to be mapped. Stoms

(1994) provides an excellent example, relating to the terrestrial species richness of vertebrates in southern Idaho, of how the scale used for data collection and mapping can influence the validity and usefulness of the final map (Figure 7.5). Here it can be seen that, with the use of

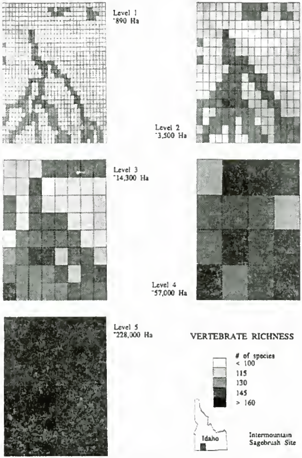


Figure 7.5 Species Richness Maps Showing Absolute Richness of Vertebrates in Part of Southern Idaho (USA) at Five Sampling Unit Sizes (from Stoms, 1994)

890 hectare cells a reasonably accurate perception of the distribution of vertebrate species can be obtained (level 1), but by the time cell size is increased to 57,000 hectares (level 4) then the information as portrayed for this part of Idaho is virtually useless. To briefly illustrate scale variability in the marine situation, we could envisage that maps showing legal or exclusive economic zones (EEZs) could be compiled at quite a small scale (perhaps 1:5 000 000, but depending on the region being mapped) whereas, at the other extreme, maps showing the possible configuration of mariculture facilities at a particular location could be at a scale of perhaps 1:2 000. Figure 7.6 provides a good indication of the scale variations which might need consideration.

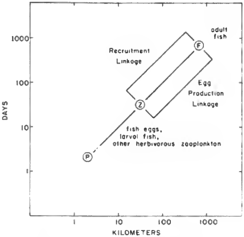


Figure 7.6 Typical Time and Space Scales Associated with Plants (P), Zooplankton (Z) and Pelagic Fish (F) (from Rothschild, 1986)

A further way in which the mapping scale chosen can be an important decision relates to the fact that, to instigate changes of scale in a GIS, can be very difficult due to the problem of "generalisation". Briefly, this means that once mapping entities are drawn at a given scale, then it is difficult to change this scale without the map either becoming too cluttered or too sparse, i.e. simply because the degree of detail varies at each scale. Thus the zooming in or out from a given map can only be realistically accomplished over a relatively small range of scale variations.

It is recommended that before a database is set up, then some thought should be given to the likely mapping scale to be used. It also seems sensible that, for any given fisheries management area, then the marine space should have been divided up into a hierarchy of nested cells. In other words surveying or mapping of any marine related variable, could take place at any chosen scale, and if a consistent hierarchy has been used, then comparisons or overlay functions can

routinely be executed using established cellular areas. With regard to cell size or the scale of mapping then certainly before the final mapping output for any specific purpose was required, some experimentation should have been carried out.

7.3 Potential Database Areas for a Marine Fisheries GIS

Since the subject area of marine fisheries is so wide and since it has been shown that a GIS offers the potential to perform a wide variation of management related functions, then of prime concern is how best to subdivide the subject into recognisable "database areas". Obviously there is no right or wrong way of doing this. Caddy and Garcia (1986) identified eight main areas to which fisheries mapping could be applied (Table 7.1), and undoubtedly there could be others. The way which is chosen will clearly depend on a variety of factors such as those listed in Table 7.2.

Table 7.1 Fisheries Applications of Mapping Techniques as Identified by Caddy and Garcia (1986)

* Mapping of local environments and production systems.
* For designing statistical data collection surveys.
* For planning scientific resources surveys.
* For preparing inventories of resources.
* For the elaboration of management plans.
* Mapping fishing effort distribution and fishing grounds.
* Mapping in support of international agreements.
* For remote sensing and subsequent mapping.

Table 7.2 Factors Determining the Way in Which a Marine Fisheries GIS Could be Subdivided into Database Areas

* The scale of the marine area which was being managed.
* The resources which were available to fund the GIS.
* The degree of urgency behind the need for fisheries management.
* The purposes to which the GIS were to be allocated.
* Any individual or departmental perceptions as to fisheries management needs or priorities.
* The adoption methods chosen to implement the GIS.
* The ways in which the subject field were already being subdivided - perhaps for other purposes.
* The type and quantity of relevant data which already existed.

Our approach to this problem of dividing up the subject will be from the perspective of implementing a national or regional fisheries management policy, i.e. the approach will be practical rather than academic or theoretical. There will thus be a presumption that data from the whole subject field, plus several linked but perhaps more marginal fields, might need to be

included. What we are not doing therefore is approaching the subject from the viewpoint of perhaps an individual fisherman, fishing company, local fishing community or any sub-sector of the activity, or from the viewpoint of an academic institution interested solely in theoretical modelling or simulation. Obviously, any of these sectors could still find a marine fisheries GIS to be of use, but it would not encompass the same functional requirements or emphases.

Meaden (1993) identifies seven database areas which must be of broad relevance to any marine fisheries GIS, and these can usefully form the basis of the subdivisions used in this chapter. However, it is important to note that the seven areas chosen only represent a starting point. Once data from primary or secondary data collection initiatives had started to accrue, then it would soon become apparent that further subdivisions of the database areas would be necessary to meet the real management needs of the time. This need would be reinforced if or when it was found that links to other relevant data sets could be obtained, i.e. with an implication that not all of the datasets would need to be held by the fisheries management team. In fact it is likely that, as the marine GIS became more complex, only a minority of the data needs would be held "in-house", with the majority being accessed via various WAN's. The database areas identified in this section are thus simply a means of classifying data into a range of spatio-related ideas, and within each there would be a huge range of potential subjects. GIS will allow for the functionality of cross border analyses between the seven main database areas identified.

Within each of the database areas, our approach is (i) to look at the range of factors that the area includes in terms of major topics or subjects, (ii) to exemplify the type of non-GIS published spatially related work or research being undertaken, (iii) to review the types of management problems and perspectives, and, remembering that potential data sources have been outlined in Chapters 2 and 3, (iv) to suggest ways in which any specific data could be mapped, modelled or analysed. Our examples of spatially related fisheries work have been chosen for their variety of mapping techniques, and in many cases the original captions have been retained as a means of explanation. The main aim is to be suggestive rather than speculative. It is important that the ideas given on the uses of GIS are both realistic and practicable. It is also important to realise that, within and between each of the seven suggested database areas, GIS technology will allow for not only descriptive analyses of current or past situations, but also for prescriptive formulations based on variable simulations and/or modelling. Given these aims, and the breadth of the GIS potential, then only a small range of possibilities can be introduced here.

7.3.1 GIS and Marine Water Conditions and Habitats

Water qualitative parameters on which data might be collected include temperature, salinity, DO levels, water colour/algae content, turbidity, sea currents, density, etc. As well as these marine qualitative parameters, for the success of fisheries management and resource sustainability, it is important to have an indication of habitat types and their spatial disposition. This would include acquiring data on various ecosystems such as coral reefs, sea grass beds, estuarine areas, upwellings, mangroves, sandbanks, etc. It would also include having a detailed indication of oceanographic factors such as sea bottom types, the location of tidal and other fronts plus major and minor gyres, prevailing sea currents, turbidity and bathymetry. Eventually it might be

desirable to have more general climatological and oceanographic data concerning perhaps climatic variables, tidal information, wave height, etc. The main sources of data for any of these parameters is shown in Table 7.3.

Table 7.3 Likely Data Sources on Marine Water Conditions and Habitats

* Marine trawl surveys.
* Marine acoustic surveys.
* Oceanographic databases.
* Hydrographic charts (paper and digital).
* Tide tables.
* Topographic mapping (paper and digital).
* Specialist thematic maps or atlases.
* Remotely sensed data - especially data from these sensors:
  Advanced Very High Resolution Radiometer (AVHRR), Coastal Zone Colour Scanner (CZCS), Radar altimeter data, Sea-viewing Wide-Field-Of-View Sensor (SeaWIFS), High-resolution Multifrequency Microwave Radiometer (HMMR), Ocean Colour Monitor (OCM). Synthetic Aperture Radar (SAR).

Spatially variable water qualitative data readings may already form the basis of isoline or other maps, and new data being gathered would form the basis of additional databases from which new maps could be compiled. Thus, it is important to note that there already exists a vast amount of marine survey data consisting of geo-referenced point measurements and which, through the use of GIS, could form the basis of interpolated mapped surfaces. GIS manipulative functionality will allow for the easy production of, for instance, spatial correlation or time series analyses between and within any of the mapped variables. RS and acoustic techniques are allowing for huge datasets to be built up on sea bottom typology, and again GIS will enable the mapping of this, as well as the construction of digital terrain models (DTM) which might allow for the visualisation of perhaps relationships between depth and various habitat types. Although there is abundant evidence of the importance of water qualitative factors to fish growth and recruitment, e.g. Rothschild (1986), Gulland (1988), Mann (1993) and Cushing (1995), few detailed longer term spatially based analyses have previously been possible.

Our first example of how GIS could have been effectively utilised concerns the type of modelling study carried out by Werner et al (1993). As Figure 7.7 shows, the authors were attempting to simulate, by the use of passive particles, the fate of the early life stages of cod or haddock which spawn on the Georges Bank in the North West Atlantic. Time series GIS can easily be implemented by the use of temporally interpolated data, and the GIS could usefully have shown various indicators of the degree of relationship between the passive particles and the current speed and direction. Any type of modelling which involves diffusion processes can be comparatively easily simulated. So, for instance, Thomson et al (1992) proposed a conceptual model to show the effect of the North Pacific currents on sockeye salmon (Oncorhynchus nerka) migration routes and their likely landfall location (Figure 7.8) and, as inferred in their paper, this could have been expedited by the use of GIS.

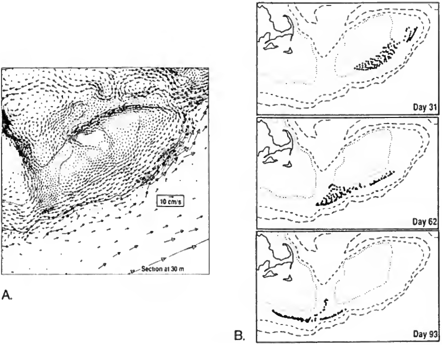


Figure 7.7 Horizontal Disposition of Particles at 30 Metre Depth on Georges Bank, N.W. Atlantic Ocean, Compared With the Main Currents at the Same Depth (from Werner et al, 1993)

Figure 7.9 shows data published by D'Amours (1993) on temperature and oxygen levels for August, 1991 in the Gulf of St. Lawrence. In his study D'Amours sought to show the relationship between the distribution of cod, water temperature and oxygen levels in the Gulf, and for this GIS could have been applied to advantage to achieve mapped interpolated surfaces for use in any type of spatial auto-correlation analysis. Traganza et al (1983) have used satellite data to measure water temperatures in the upwelling off California. From associated shipboard observations they have fitted inferred nitrate readings to the temperature isotherms (Figure 7.10). Obviously GIS based techniques would have allowed for the expansion of this work so as to either incorporate other water qualitative variables, or to have established relationships between water quality and measurements of fishery resources distribution and biomass. Recently, both Mann (1993) and Cushing (1995) have emphasised that it is vital to make spatial analyses

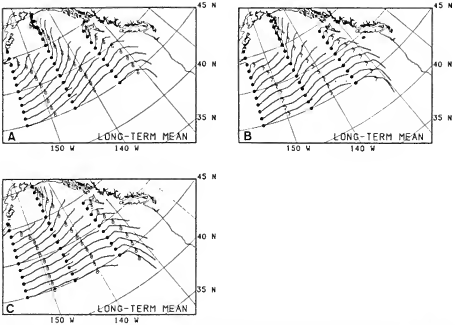


Figure 7.8 Simulated Movements of Sockeye Salmon in the North Pacific According to Different Start Locations (A = June; B = July; C = August) (from Thomson et al, 1992)

between various factors relating to climate, physical oceanography, marine food chains and fish stocks - the use of GIS would greatly enhance our capacity to do this. Finally, examples of gathering data for bathymetric mapping, via the use of acoustic surveys, are given in Mills and Perry (1992) and Somers (1992). The storage of this digitised depth data into a GIS, will allow for its immediate functional use.

7.3.2 GIS and Natural Marine Resources

Here the essential concern is with the mapping and analyses of quantitative or qualitative estimates of marine biomass distributions or densities. Separate databases can be established for any particular geographic area, and/or at any particular time(s), covering criteria such as individual fish species, sea mammals, planktons, cephalopods, shell fish, crustaceans, etc. Obviously these could be further subdivided into genera, subspecies, etc. Most previous mapping

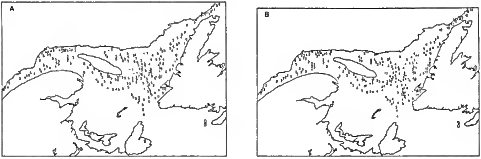


Figure 7.9 **(A) Bottom Temperatures and (B) Bottom Oxygen Levels (Mg/l) in the Northern Gulf of St. Lawrence, Canada for August-September, 1991 (from D'Amours, 1993)**

of species distribution has simply utilised some sort of quantitative location symbol, such as proportional circles or various classes of shading, to illustrate species density or distributional variations. With the use of specialist GIS algorithms it would be possible to refine distribution maps so that they showed both species density variations and statistical variance (see Section 7.2.4). As also inferred in section 7.2 above, the frequency of mapping species distributions will be a function of both the temporal variability of the distributions and the purposes to which the maps are being put plus, of course, the availability of new data. Table 7.4 gives an indication of the likely sources of data for maps showing biomass distributions.

Table 7.4 Likely Data Sources on the Density or Distributions of Natural Marine Resources

* Marine trawl surveys
* Marine acoustic surveys
* Specialist maps or atlases
* Government and other marine research institutes
* Commercial catch records
* Remotely sensed data (satellite or airborne)
* Specialist fisheries or biologic databases

The usual reason for doing resources surveys or analyses is to gather quantitative data which may be of help in estimating biomass and establishing not only yield potential, but changes in stock numbers or indications of the biological productivity of the water. Not only would GIS be able to provide additional graphical output on this type of information, but it would also allow for more refined analyses such as time series correlations, inter species correlative analyses,

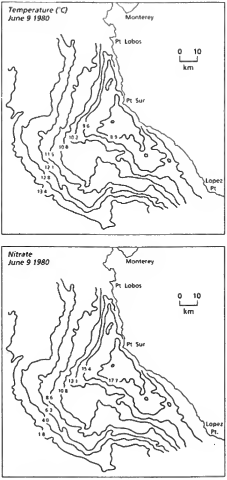


Figure 7.10 Inferred Nitrate Readings from Temperature Isotherms off the Southern California Coast, USA (from Traganza et al, 1983)

contiguity analysis (as an aid to establishing patterns of adjacency) and analyses such as the nearest neighbour index which allows for objective indications of the degree of clustering or

dispersal of or between marine species. Clearly all these analytical functions can be carried out between, for instance, fishing catch/effort indicators and biomass quantitative factors.

As well as the mapping of biomass density or distributions, this database area must concern itself with the study of those natural and anthropogenic biomass processes which have a strong spatial element. Examples of these would be:

(a) Patchiness - the propensity for both phyto- and zooplankton to aggregate in non-homogeneous patches. The schooling of fish may also be considered to be a kind of patchiness.
(b) Blooms - the huge growth of plankton which occurs mostly in the early spring following increased insolation. This may also refer to other types of rapid reproduction such as the development of toxic algal blooms.
(c) Migrations - many species incorporate migrations into their life cycles. These may be diurnal feeding migrations or annual or periodic spawning migrations.
(d) Displacement - this refers to the change in species dominance which might occur over time in a given area. An example would be the displacement of anchovy by sardines in the Peruvian Current of the eastern Pacific, or the displacement of herring by gadoids in the North Sea.
(e) Enhancement - referring to the selective stocking of marine areas with organisms which have been reared in captivity.
(f) Extinctions - there have been a number of recorded occasions when, for various reasons, species have been found to no longer occur in an area. Clearly it is in any fisheries manager interest to establish the causes for this.
(g) Recruitment - the number of recruits joining the adult stock each year is notoriously variable. More knowledge on the dynamics of this process is of paramount interest to most fisheries managers.

Explanations and understandings of these processes are essential to the long term viability of many fisheries, as well as to the well being of marine ecosystems. Since the processes incorporate temporo-spatial change at various scales, then it is likely that the functionality of GIS's will prove the only way of successfully modelling, simulating or recording the variety of factors underlying any single process.

Studies which exemplify the mapping of marine biomass resources take a large number of forms. They may start from fairly basic accounts which seek only to show a specific species distribution and/or density. They may then attain sophistication by perhaps showing a density or distribution relative to some former temporal period or show a sequence of temporal changes for the species. Spatial analyses might then go on to portray relationships, either between a species distribution and some water qualitative or environmental parameter(s), or between the distribution of one species and one or several others. At a most sophisticated level GIS could be used in the simulation or modelling of factors concerning a species spatial potential or any

intra- or inter-species relationships. In the following paragraphs examples of some of these types of potential GIS mapping are given.

Examples of works which show, in a selected variety of ways, relatively straight-forward biomass density and distribution, and for which GIS could have been usefully employed, include Carpentier et al (1989), Isaev and Seliverstov (1991), Lago de Lanzos et al (1993) and Armstrong and Briggs (1993). Some mapped distributions may be extremely basic in that they simply allocate numerical quantities to cells. This is the method used by both Carpentier et al and Isaev and Seliverstov to show respectively the distribution of cod in the English Channel (Figure 7.11) and blue whiting to the west and north of the British Isles (Figure 7.12). Lago de Lanzos plots the density distribution of mackerel eggs in the southern Bay of Biscay in 1990 (Figure 7.13), using two forms of mapping representation. The use of GIS in either case would have allowed for a variety of mapping types, as well as many statistical manipulations and analyses either between cells or between similar maps constructed for successive time periods. Likewise, the Armstrong and Briggs data (Figure 7.14) could have formed the basis of temporal spatial distributional change analyses had a GIS been used.

Studies which show the relationship between a biomass distribution and a water qualitative or environmental factors include Iversen et al (1993), who showed the relationship between anchovy (hatched areas) and sea surface temperatures in the Yellow Sea (Figure 7.15) and Brunetti and Ivanovic (1992), whose study related the occurrence of the early life stages of the squid (Illex argentinus) to water temperature, plus the positions of the Brazil Current and the continental shelf (Figure 7.16). The capacity of GIS to function optimumly in a mode which involves overlaying various classes of data, makes GIS an excellent medium to analyse the types of relationships shown in these examples. The benefit of this type of analytical ability would also have been useful in the situation as exemplified in the study by Shuntov et al (1990) who related fish biomass to the abundance of macroplankton in the Sea of Okhotsk (Figure 7.17).

Besides being of use in the plotting of various types of biomass distribution, GIS functionality can be applied to statistical and resource modelling situations. Thus Simard et al (1992) investigated the possibilities of using various statistical procedures to deal with estimation problems in the spatial autocorrelation of shrimp samples in the Gulf of St. Lawrence. Since they had very detailed data, then, given an appropriately sophisticated GIS package, this complex type of kriging work would prove relatively straight-forward - indeed the maps they produced might well have been produced using a simple GIS (Figure 7.18). Crawford and Fox (1992), using echo sounding data and a graphics program called SURFER, showed a number of ways in which fish biomass could be portrayed - Figure 7.19 shows one example. This work could readily have been accomplished by most GIS packages. There have also been a large number of marine fisheries simulations which have attempted to show how dispersal patterns occur (or might occur) over time for various marine species. Figure 7.8 (in section 7.3.1) showed work carried out by Thomson et al (1992), and MacCall (1990) showed the basis of a diffusion model to simulate the transport of anchovy eggs, from three starting places of the coast of southern

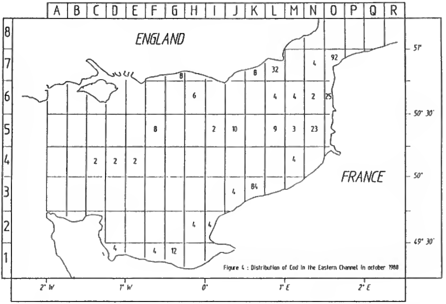
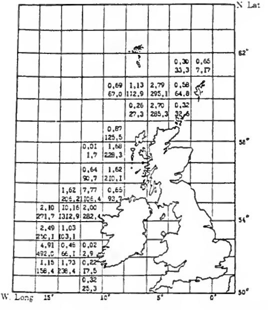


Figure 7.11 Distribution of Cod in the Eastern English Channel - October, 1988 (from Carpentier et al, 1989)

California, under the influence of both Ekman and geostrophic flow patterns (Figure 7.20). The use of time series GIS programs would allow this type of modelling under an almost infinite number of variable conditions.

7.3.3 A GIS for Fisheries Management, Allocation and Regulation

The management and regulation of fisheries is desirable for a number of disparate reasons. Although the obvious reasons are related to the direct necessity to guarantee that fish stocks are sustainable, i.e. so as to ensure the maintenance of the fishing industry, the back-up industrial sector and to ensure the continuance of supply, there are also less obvious reasons. Thus management is necessary, in an economic sense, to ensure a fair distribution of the resource and to help improve the efficiency of the industry. From a social sense it may be desirable in order to maintain the continuance of fishing communities, or for the protection of public health. And from the environmental viewpoint, there are a number of important management perspectives,



Total population and biomass distribution of the Hebridean-Norwegian school of blue whiting by quadrant. In each quadrant, the upper number is the number of fish in millions; the lower number represents thousands of tons.

Figure 7.12 Distribution of Blue Whiting to the West and North of the British Isles (from Isaev and Seliverstov, 1991)

e.g. in order to enhance marine systems biodiversity it is essential that monitoring, protection and possibly improvement tasks are undertaken, and it is also important to realise that a total ecosystems approach to fisheries sustainability is now being seen as desirable (Alexander, 1993). Management is additionally necessary in the sense that fisheries are one of several economic and social activities which may be competing for marine space. Further details on spatial aspects concerning fisheries management and regulation can be found in Arnason (1991), Morgan (1991), Waters (1991), Hinds (1992), Symes (1992), Pearse and Walters (1992), Green and Stockdale (1993), Holden (1994), and the journal "Marine Policy" is very informative. Management policies emanate from various hierarchical levels. At an international scale fisheries policies may be activated by institutions such as the United Nations or the European Community. At other levels there will be national, regional and even local sources of management decision - indeed there are moves towards encouraging fisheries management to operate at the local

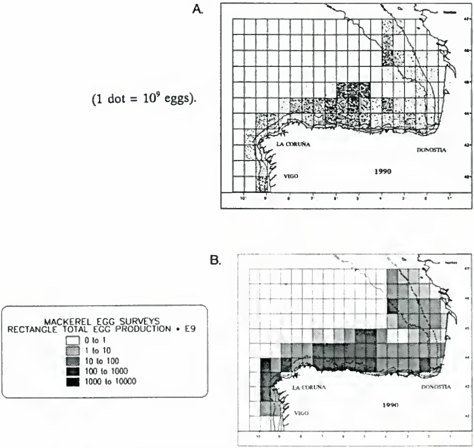


Figure 7.13 Dot Map Showing Total Mackerel Egg Abundance in a 1990 Survey, and choropleth Map Showing Daily Mackerel Egg Production in the Same Period - in the Southern Bay of Biscay (from Lago de Lanzos et al, 1993)

community level (McGoodwin, 1990, Siar et al, 1992, Dyer and McGoodwin, 1994). Many of the regulations are formulated by multilateral regional fisheries bodies, examples of which are shown in Table 7.5. At whichever level the policies come from, there will be a need to set out

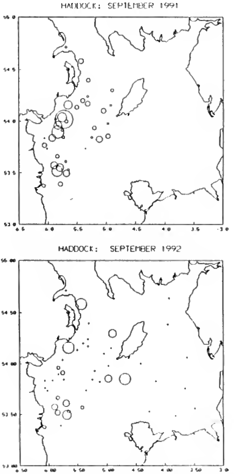


Figure 7.14 Distribution of the 1991 Year Class of Haddock in the Irish Sea for September, 1991 and 1992 (from Armstrong and Briggs, 1993)

rules, to monitor them and, if necessary, to adjudicate or arbitrate as to their compliance. Different hierarchical levels will usually be entrusted with making management policies covering

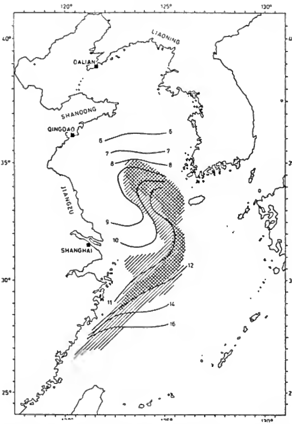


Figure 7.15 Mean Surface Temperatures and Distribution of Anchovy in the East China Sea During March (from Iversen et al, 1993)

differing spatial scales, and of course it will be necessary to make agreements on a bilateral or multilateral basis among and between the various levels. The original sources of data for a GIS which outlines management and regulatory areas or zoning will usually be from legal documentation or bulletins produced by the various authorities concerned, although a are shown in Table 7.5. At whichever level the policies come from, there will be a need to set out rules, to monitor them and, if necessary, to adjudicate or arbitrate as to their compliance. Different hierarchical levels will usually be entrusted with making management policies covering differing spatial scales, and of course it will be necessary to make agreements on a bilateral or multilateral

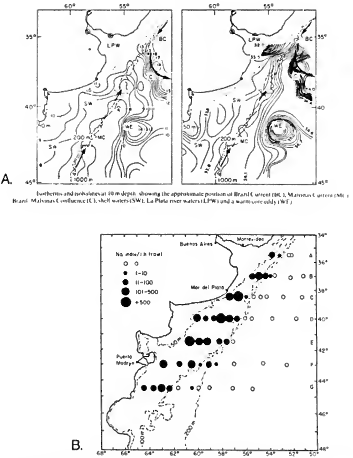
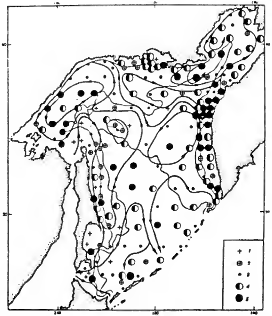
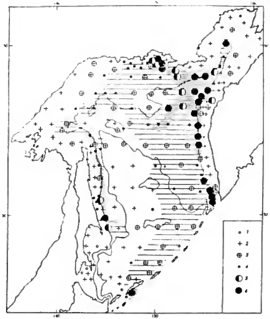


Figure 7.16 Water Qualitative Parameters (A) and the Abundance of Juvenile Squid (B) off the North Coast of Argentina in Summer, 1989 (from Brunetti and Ivanovic, 1992)

basis among and between the various levels. The original sources of data for a GIS which outlines management and regulatory areas or zoning will usually be from legal documentation or bulletins produced by the various authorities concerned, although a miscellaneous variety of



A. Distribution of macroplankton biomass in the Sea of Okhotsk, June–August 1988, mg/m^3. (1) less than 200, (2) 200–500; (3) 500–1000; (4) 1000–2000; (5) over 2000; isolines—200- and 1000-m isobaths, arrows—approximate surface circulation in 1988



B. Fish caught in epipelagic waters of Sea of Okhotsk in June and July of 1988, in tons per hour of trawling: (1) no catch; (2) less than 0.3, (3) 0.3–1.0; (4) 1.0–5.0; (5) 5.0–10.0; (6) over 10. Horizontal lines indicate echo soundings of fish, with the density of the striations reflecting the intensity of the recordings

Figure 7.17 Distribution of Macroplankton Biomass Compared With Fish Catches in the Summer of 1988 in the Sea of Okhotsk (from Shuntov et al, 1990)

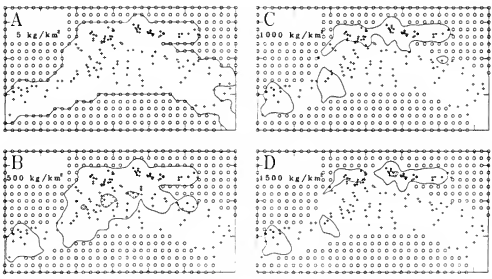


Figure 7.18 Maps to Show Shrimp Biomass Contours of 5, 500, 1000 and 1500 kg/km² in the Gulf of St. Lawrence, Canada in 1988. (+ = sampling point < 1000 kg/km²; * = > 100 kg/km²; o = non-sampled areas)

secondary sources often provide the necessary information, including most of the regional fisheries bodies and maritime atlases.

Table 7.5 Regional Fishery Bodies Covering the Atlantic Ocean and Adjacent Seas (Source: The World Bank, 1992)

* International Council for the Exploration of the Seas (ICES)
* North-East Atlantic Fisheries Commission (NEAFC)
* North Atlantic Salmon Conservation Organization (NASCO)
* Northwest Atlantic Fisheries Organization (NAFO)
* General Fisheries Council for the Mediterranean (GFCM)

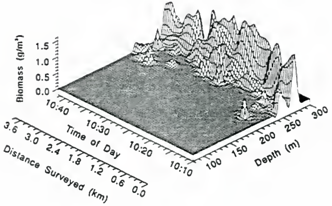


Figure 7.19 3-D Plot of Water Column Biomass Along a 3.5 km Track Using Data from an Acoustic Survey (from Crawford and Fox, 1992)

* Fishery Committee for the Eastern Central Atlantic (CECAF)
* Western Central Atlantic Fishery Commission (WECAFC)
* Regional Fisheries Advisory Commission for the Southwest Atlantic (CARPAS)
* International Commission for the Conservation of Atlantic Tunas (ICCAT)
* International Commission for the South East Atlantic Fisheries (ICSEAF)

It is important to point out that the tools for management, allocation and regulation may be either directly or indirectly spatially related. Directly spatially related regulation is where all or part of a fisheries area is partitioned in some way for management purposes. Thus, for instance, King (1995) shows how an ecosystems approach to management may set aside various "Marine Protection Areas" in which access and exploitation are controlled (Table 7.6). Clearly, it would be a simple task to map these regulation zones. Regulation may be indirectly spatially related in the sense that the regulation itself has nothing directly to do with specific areas, e.g. limiting the efficiency of types of fishing gear, but the regulation or management policy could well be assigned to specific spatial areas.

Table 7.6 Examples of Marine Protection Areas (adapted from King, 1995).

ZONES	ALLOWANCES
* Preservation.	No access.
* Wilderness.	Access allowed, but no exploitation.

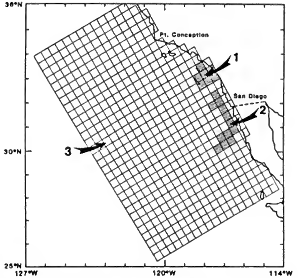


Figure 7.20 Cell Diagram for a Transport Simulation of Anchovy Eggs in the Pacific Ocean off Southern California, USA (from MacCall, 1990)

* Recreational.	Regulated amateur fishing.
* Traditional fishing.	Subsistence fishing by people living on coast.
* Scientific.	Authorised research purposes.
* Experimental.	Fishing controlled at different levels to assess effects of exploitation.

The actual division of marine space for management or regulation can take several forms. Initially, under a natural classification, marine areas often form obvious units such as "the Mediterranean Sea", the "Black Sea" or the "Persian Gulf". Then there has recently been a move towards recognising marine areas in terms of "large marine ecosystems" (LME's), i.e. areas of the sea which have large scale unified hydrographic regimes and trophically related populations of marine organisms. Figure 7.21 shows the LME's which have currently been defined. Very recently the concept of the marine catchment basin (MCB) has been proposed (Caddy, 1993). This refers to the idea that an important way of examining marine areas, especially closed or semi-enclosed seas, is via an appreciation that a river basin is inextricably linked with the marine area into which its waters flow. Thus, for instance, the problems which are so obvious in the Black Sea stem in large part from inputs which are received there from inflowing rivers such as the Danube, the Don and the Volga.

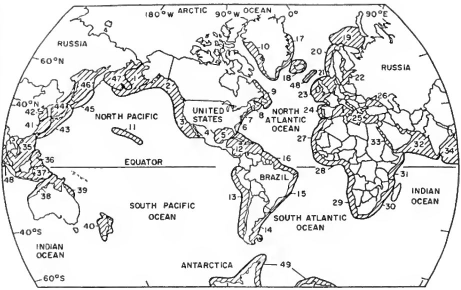


Figure 1. World map of Large Marine Ecosystems.

Key
1 Eastern Bering Sea
2 Gulf of Alaska
3 California Current
4 Gulf of California
5 Gulf of Mexico
6 Southeast US Continental Shelf
7 Northeast US Continental Shelf
8 Scotian Shelf
9 Newfoundland Shelf
10 West Greenland Shelf
11 Insular Pacific–Hawaiian
12 Caribbean Sea
13 Humboldt Current
14 Patagonian Shelf
15 Brazil Current
16 Northeast Brazil Shelf
17 East Greenland Shelf
18 Iceland Shelf
19 Barents Sea
20 Norwegian Shelf
21 North Sea
22 Baltic Sea
23 Celtic-Biscay Shelf
24 Iberian Coastal
25 Mediterranean Sea
26 Black Sea
27 Canary Current
28 Guinea Current
29 Benguela Current
30 Agulhas Current
31 Somali Coastal Current
32 Arabian Sea
33 Red Sea
34 Bay of Bengal
35 South China Sea
36 Sulu-Celebes Seas
37 Indonesian Seas
38 Northern Australian Shelf
39 Great Barrier Reef
40 New Zealand Shelf
41 East China Sea
42 Yellow Sea
43 Kuroshio Current
44 Sea of Japan
45 Oyashio Current
46 Sea of Okhotsk
47 West Bering Sea
48 Faroe Plateau
49 Antarctic

Figure 7.21 World Map of Large Marine Ecosystems (from Alexander, 1993)

For a long time now, most of the major marine areas have been officially sub-divided into fisheries zones by some of the main fisheries regulatory bodies. Thus for instance, there are official ICES zones which cover much of the north east Atlantic area, and there are NAFO regulatory areas in the north west Atlantic (Figure 7.22). Other forms of spatial division, as

manifest from a legal viewpoint, are the 200 mile Exclusive Economic Zone (EEZ) and the Exclusive Fishery Zone, and these might form the mapping boundary for any national fisheries GIS. Figure 7.23 gives examples of these zones as they apply in the south west Pacific area. Within any of these units of marine space, for both management and regulation purposes, it may be necessary to further subdivide the area, possibly using a hierarchical nested cell structure, i.e. a more refined version of the "ICES rectangles" which are presently used in the North Sea.

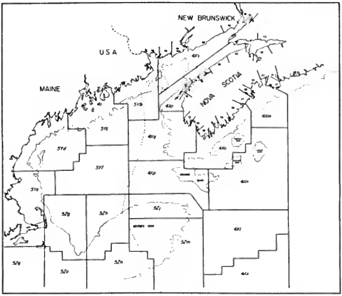


Figure 7.22 Example of Northwest Atlantic Fisheries Organization Divisions and Subdivisions

Once the unit areas for management have been established, then the areas form the basic units into which variables of regulation are plotted. There are a large number of ways in which regulation is administered which we cannot go into detail here. However, we should note that the type of regulatory variables which we are conceiving of include catch regulations (which might include factors such as net mesh size, length of drift net, season of fishing, etc,) plus fishing rights, quotas and total allowable catches, closures, plus indices of fish availability such as maximum sustainable yield or even the amount of restocking per cell which had taken place. The different ways of recording and mapping these regulatory variables would need to be considered before any GIS output could be obtained. It should be mentioned here that fishing fleet tracking using satellite systems is now seen by many governments as the most practical way

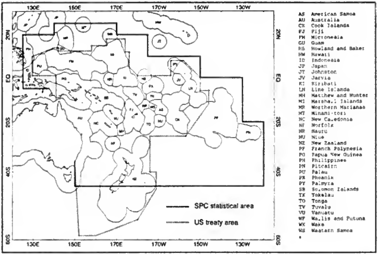


Figure 7.23 200 Mile Exclusive Economic Zones in the South Western Pacific

of maintaining checks on the operations of fishing vessels, and this "spy-in-the-sky" system is likely to be increasingly utilised, especially since the monitoring of fishing for migratory and straddling stocks has now been agreed upon. If these system store their records, as they have the capability to do, then it will form a valuable GIS data resource for mapping the logistics of specific vessel activity.

An initial example of how GIS might be employed in delimiting access rights is given by Bidi (1993) with reference to the Gulf of Guinea coastal states in West Africa. He suggests that the twelve coastal nations from Mauritania in the west to Nigeria in the east, will need to have a degree of "flexible co-operation" in their approach to managing the limited fish stocks of the area. In the neighbouring area to the north, i.e. between Guinea Bissau and southern Morocco, management of the prolific fish stocks urgently needs to be strengthened because of the almost total lack of control on access rights (Goffinet, 1992). In this area, the rich upwelling of the Canaries currents ensures a high natural productivity and thus the fisheries potential is huge. However, the nearshore coastal states are both thinly populated and comparatively impoverished. Although a regional management organisation has been set up, the Committee for East Central Atlantic Fisheries (CECAF), it has no enforcement capabilities. The area has been divided up into the divisions as shown in Figure 7.24, with the coastal states being responsible for specific areas. These divisions will form the basis of data gathering units to which GIS functionality should be able to usefully contribute. The granting of territorial use rights for small scale fisherfolk in almost any country, under community based management schemes, is seen as a

major way of enhancing the livelihood of the people involved (Ruddle, 1987). The examples in this paragraph all involve rights of access and the right to determine levels of fishing effort and catches with the necessary legal backing. The management of such schemes would usefully employ GIS techniques at micro or macro scales, so allowing for GIS learning to occur in conditions where data gathering was unlikely to be too overwhelming.

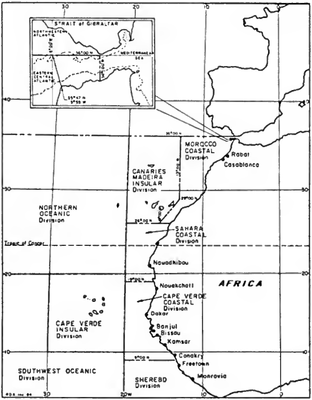


Figure 7.24 Committee for East Central Atlantic Fisheries (CECAF) Divisions off the North West African Coast (from Goffinet, 1992)

In the small and heavily overfished North Sea, Symes (1992, p.336) recognises that "effective central control is essential", and that this must incorporate the need to vary the system of

regulation to suit ever changing conditions of stock availability and consequent Total Allowable Catches (TAC's). Similarly, in the Peruvian and Chilean upwelling coastal waters, which have witnessed huge stock fluctuations from both natural and human intervention reasons, Caviedes and Fik (1993) advocate strict resource management and restrictions on fish capture. In a final heavily fished area, that off the eastern seaboard of China, we illustrate (Figure 7.25) how the marine area has been zoned such that certain fisheries related activities are allocated to specified zones. Each zone is managed under a complex set of regulations as laid down under the 1986 Chinese Fishery Law, and as explained by Wang and Zhan (1992). In all of these studies, which relate to heavily fished areas, GIS has the functionality to address a range of aspects of management.

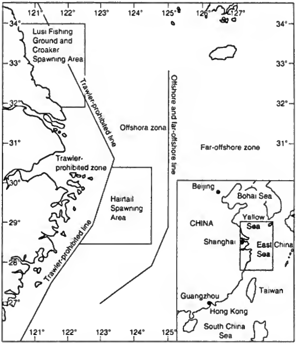


Figure 7.25 Fishery Zones in Part of the East China Sea (from Wang and Zhan, 1992)

7.3.4 GIS and Fisheries Effort and Catches

This section covers "effort" and "catches" since, although they are obviously describing and measuring two distinct variables, there are many ways in which they are both strongly related and inextricably linked. It is also important to mention here that in some ways it is difficult to separate the previous section (7.3.3) on management and regulation from this database area. This is because nowadays a large proportion of the world's fisheries have their effort and catches managed by the various regulatory bodies which have been referred to, and there is plenty of evidence that recent regulatory measures have had an impact on fisheries effort and catches, e.g. Bergin and Howard (1992) and Symes (1992). However, from a GIS organisational viewpoint, it is easier to separate management from effort and catch factors. Thus our consideration of management was mostly from the viewpoint of establishing zonations for different regulatory purposes, whereas our considerations relating to effort and catches relates to the measurement of these and to the ability of assigning measurements independently to any spatial zones.

Any evaluation of fishing effort encompasses a variety of techniques and considerations. The common forms of measurement are by indices such as those shown in Table 7.7. At a different level it is also possible to measure effort in terms of the regional or national investment in the fisheries industrial structure and infrastructure. So it can be conceived that there must be varying returns from the fishing activity which are related in some way to the total amount of capital invested in the industry. At one scale investment may be in large scale infrastructure such as fishing harbours, freezing plants, repair yards, etc. At a very different scale, effort may be evaluated in the form of the numbers of small fishing craft which are used by local sea-shore communities. At either scale, the amount and distribution of fisheries investment should form part of the basic data which would be collected for GIS purposes. It is important to note that so-called "technology creep" is occurring whereby inputs of effort are becoming more effective due to the adoption on fishing vessels of technological aids. This often makes it difficult to carry out time series analyses or inter-regional comparisons on fishing effort. Effort is increasingly being subject to monitoring and regulation, and this is being effected by means such as licence limitations, log books and satellite monitoring of vessel activity. Hilborn and Walters (1992) and Anon (1993) both give very good descriptions of the modern practices and problems connected with evaluating and monitoring fishing effort, the former covering all aspects and the latter as it relates to European Community countries.

Table 7.7 Some Common Ways of Measuring Fishery Effort

* Weight of fish caught per hook per hour.
* Number of lobsters caught per trap per day.
* Weight of fish caught per hour of trawling.
* Number of hours a vessel is at sea.
* Proportion of hooks on a long-line which have caught fish.
* The working cost of maintaining a vessel at sea per time unit.
* Catch per unit of a vessel's horsepower.
* Catch per man hour fished.

The monitoring of catches must be one of the core tasks in any fisheries management program. There are a number of obvious reasons for this which are mostly concerned with gaining information on the longer term trends in the welfare of the stock. For GIS use, and for other purposes, it is useful if the catch data per vessel can be disaggregated as much as possible, i.e. by species, by place of capture, time of capture, method of capture, etc. For research purposes additional data is also necessary such as condition, age and size of individuals in the stock. It is also normal to record catch data (or fish production data) by species or product types (chilled, fresh, frozen), or by commercial group sizes, at the ports of landing. If a wide range of categories of catch data is made, then there is the potential to present information in a useful way; unfortunately this has not always been the case in the fishing industry because fishery operations are carried out in a wide range of different communities which themselves are often scattered around long coastlines, and which utilise a variety of recording methods. Additionally, it has often proved too complex and expensive to even justify setting up the necessary data gathering mechanisms.

The acquisition of data or information on fishing effort and catches is often difficult to achieve in a form which is useful to a GIS since, as inferred above, it is often of dubious accuracy or is incomplete, it will seldom be disaggregated to a desirable degree and it will often only be available in very mixed formats, i.e. making time series, or inter-area, analyses impossible. Data which is available is usually held by the appropriate government fisheries department for a region or country. Sometimes individual ports may have local statistics, as may various fishery co-operatives. Marine research institutes might have data available, though this is more likely to refer to stocks or survey catches rather than to commercial catches. It is important to note that sometimes it may prove possible to use proxy data to estimate likely catches, especially where fishing is carried out at a subsistence level. In attempting to secure catch data it should not be forgotten that many catches may be made by licenced (or unlicensed) foreign vessels. In some fisheries by-catches may need to be considered, or estimates might need to be made for discards at sea.

It is not necessary to give many specific examples of the mapping of effort or catch since these will be like many of the other maps shown, i.e. spatially distributed proportional circles or shaded choropleth cells. Meaden and Kemp (in press) show a programme which will be specially adapted to a commercial GIS package, and which is conceived so as to portray either catch or effort data which has been derived from GPS locational output. Here, the intention is to show the trawl path for each individual haul, and to show the catch data from this haul. Aggregations of the catch data can then be made which can be allocated to either cells or to other unit areas of management (Figure 7.26). It will clearly then be possible to use the GIS capabilities to ascertain any spatial relationships which might exist between catch or effort and any of the other database variables, e.g the GIS can be asked "What is the relationship between unit of effort and sea bottom type in area x?".

Regarding point effort capitation (the amount of fisheries investment made at any one place), Symes (1992) produces two maps (Figure 7.27) which show UK demersal fish landings for 1975 and 1986, i.e. before and after the imposition of the 200 mile EEZ. GIS could usefully be

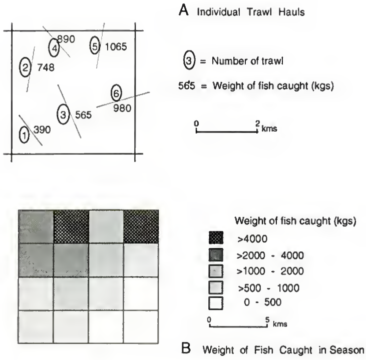


Figure 7.26 Hypothetical GIS Output to Show Fishery Catches (or Effort) by Trawl Hauls for Specific Areas

employed in any analyses of effort variation, e.g. in the Symes case it would have been simple to produce a further map which showed the difference between the two maps (or the net effect of the 200 mile EEZ imposition). At a world scale, using FAO statistical data, Juda (1991) analyses changes in fish catch distribution between different temporal periods. His lengthy study produces 14 tables of figures but no maps (e.g. Table 7.8). The use of GIS would have greatly enhanced the visual interpretation of this data, and again it would have allowed for a large number of more detailed spatial and temporal analyses. Detailed maps showing the spatial distribution of catch per unit of effort (CPUE) have rarely been produced, though Miyabe and Bayliff (1990) produce a map on this topic for bigeye tuna in the eastern tropical Pacific (Figure 7.28). This map was probably produced using a commercial computer mapping package. GIS functionality would be employed in working out why the spatial variations occurred, i.e. since such maps should show that theoretically there ought to be little variation in CPUE over space.

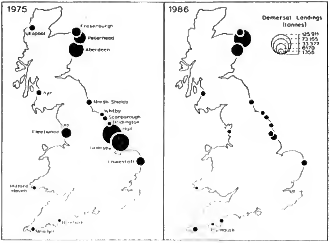


Figure 7.27 UK Demersal Fish Landings by Ports for 1975 and 1986 (from Symes, 1992)

7.3.5 GIS and the Markets for Fishery Products

Although this sector of the industry might not seem very relevant to a marine fishery resources GIS, it needs to be included since the efficient disposal of fisheries products is becoming of increasing importance and since fishery products are increasingly being disposed of (sold) at the international scale. Any considerations of markets in this section will be confined to coastal (point of unloading) markets, i.e. it will not consider any form of retail or end user markets, (except in the sense that in many subsistence economies the products will usually be disposed of directly to end users living in beach or coastal communities). We will also not be including here the transference of fish at sea from perhaps catching to processing vessels. Finally, we will not be considering fishery product marketing per se, i.e. the ways and means of best getting the products to the customers.

Markets, from the fisherman's point of view, represent the coastal unloading point. The form that the market takes will vary, as may the form in which the fishery product is unloaded. So the fish, or other form of commercial marine biomass, may be in a fresh state, may be chilled or frozen, or it may have been processed in some way. At the unloading point the product may be stored, in a suitable environment, usually for later shipment, or it may be processed and packaged into a number of forms or products. Some record of the quantity of fish which is handled in the various ways is usually kept, often by buyers from the company doing the processing or the marketing, but also by the port authorities or by fishermen co-operatives. It

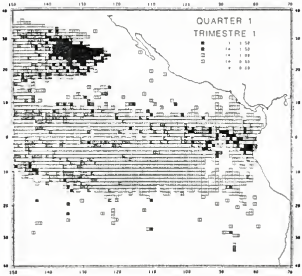


Figure 7.28 Spatial Distribution of Catch Per Unit of Effort for Bigeye Tuna in the eastern Pacific

may be expected that, since we are dealing with a natural "organic" product, then there will be large fluctuations in the market routine. This might include seasonal variations in supply, irregular changes in product requirements, variations in demand, etc., and the market for fish products may also be strongly related to competition from alternative meat protein sources. So markets for fish and fishery products are highly volatile both from a temporal and spatial perspective. This is why the mapping of markets can be very important.

For GIS purposes, market information obtained by the various port or marketing authorities, will need to be stored in a database system, from where it can be extracted for mapping. Since markets will represent coastal points, then mapping is inevitably via the use of proportional circles (as shown in Figure 7.27). Circles can represent either simple totals of fish landed at a port, or they can be progressively refined so as to show volumes of individual products or fish species. Indeed they can be mapped as proportional "pie charts" which give even more information. Where GIS can potentially be very useful is in its capacity to instantly map out both spatial and temporal changes in the various facets of the market, e.g. long term trends or fluxes in can be identified and analysed. It can also be of use in seeking to establish, for instance, under-utilised markets. Here it would a case of matching fish sale and/or consumption levels with a map showing population density and distribution, in order to identify spatial differences

Table 7.8 The Concentration of Marine Fish Catch (by percent of total tonnage) for the Top 20 States

	1970–1974	1983–1987
Top 5 states	50.12%	46.23%
Top 10 states	63.70%	62.88%
Top 15 states	73.39%	75.12%
Top 20 states	80.61%	82.36%
	1. Japan	1. Japan
	2. USSR	2. USSR
	3. Peru	3. U.S.
	4. Norway	4. Chile
	5. U.S.	5. China
	6. China	6. Peru
	7. Spain	7. ROK
	8. Denmark	8. Norway
	9. Thailand	9. Thailand
	10. ROK	10. Indonesia
	11. Korea (D.R.)	11. Denmark
	12. India	12. India
	13. Canada	13. Korea (D.R.)
	14. UK	14. Iceland
	15. Philippines	15. Spain
	16. Chile	16. Philippines
	17. Indonesia	17. Canada
	18. Iceland	18. Mexico
	19. France	19 UK
	20. Vietnam	20. Ecuador

and perhaps unexploited markets. GIS has the potential to graphically manage the disposal of fish from catching vessels to on-shore processing plants. This is very important since both vessels and plants have physical capacities which need to be finely managed. Finally, GIS can be of use in the analysis of spatial differences in species or product preferences for any specific market area.

7.3.6 A GIS for Mariculture

This need not be major sector of most marine fisheries related GIS's, though its inclusion is considered important for a number of reasons. Some countries now have either a large proportion of their total fisheries output of some species produced using culturing techniques, or the actual volume of cultured fisheries products may be high. Also, in some regions, such as the Atlantic seaboard of Canada, normal marine fish production has been severely hit and the government is turning to increased mariculture potential as one means of providing local employment and income opportunities for former fishing communities. Similarly, fish culturing

has been seen as a major way of boosting the economies of some isolated coastal regions in developed countries, and of providing both incomes and protein in coastal settlements in some developing countries (Loayza and Sprague, 1992).

It is also important to include mariculture here since the proportion of fish produced in this way is increasing faster than it is from traditional marine sources (at about 15% per annum), and this trend is likely to continue. The products of mariculture will therefore be increasingly competing in fisheries markets, and the activity itself will be competing with traditional fisheries for (and in) certain aquatic environments, near coast unprotected waters as mariculture zones offshore as well as e.g. fjords, estuaries and mangroves, and this will not be without a certain impact. For instance, Black and Truscott (1994) provide a detailed account of how the Provincial government in British Columbia, Canada, will only issue licences for mariculture after the applications have been vetted for their technical feasibility in relation to the biophysical capability of the environment. All likely mariculture sites here have been monitored and mapped in a "suitability hierarchy".

For two other reasons it is important to consider mariculture and fisheries together. The first is that both usually are under the same administration and the second is that there can be both spatial and market competition between the two.

The types of mariculture that we are considering are mainly those which is carried out in floating sea cages, and the rearing of various marine shellfish under different production systems. Cage production is usually for the intensive rearing of high value species such as salmonids, sea bass and bream. We are ignoring land based culture systems of marine species, such as that used for rearing eggs and fry to be placed in the cages, and the rearing of shrimp in brackish water coastal ponds, not because they are not important, but because these systems can best be described as being synonymous with fresh water aquaculture in terms of their input requirements, and this topic (with regard to GIS) has been recently reviewed by Beveridge and Ross, 1991 and by Meaden and Kapetsky, 1991. Also, the types of consideration regarding shrimp ponds are looked at in section 7.3.7 covering coastal zone management.

It is difficult to give explicit examples of studies where GIS might have been used, i.e. rather than traditional forms of spatial description and analyses, because there are very few mariculture studies which have sought to introduce a spatial element. Exceptions have been that of Ibrekk et al (1993), who did a nationwide search of the Norwegian coastline to assess the suitability for aquaculture, and who reported that GIS would indeed have been a useful tool to use, and the study by Silvert (1994) in which he outlined a computer based simulation model to help with aquaculture site selection. There are however, a number of aquacultural studies which have utilised various GIS, or remote sensing, techniques and these have been given as case studies in Meaden and Kapetsky (1991) and by Kapetsky and Travaglia (1995). It is interesting to note here that the World Bank has recently said, with regard to implementing small scale aquaculture:

"The appropriate use of Geographic Information Systems and remote sensing technologies in close cooperation with FAO would be highly desirable." (Loayza and Sprague, 1992; p56)

In this section we have therefore considered it useful to simply describe a number of ways in which GIS could be usefully employed as an aid to mariculture development. Kapetsky and Travaglia (1995) provide a useful list of additional ways in which GIS could be of use to mariculture.

For mariculture to be successful, it is essential that the sea cages, or the artificial shellfish beds, are located correctly. Here correct location can be considered both from a macro and micro viewpoint, i.e. a good location perhaps somewhere along hundreds of kilometres of coastline, or a good location within a fjord, estuary, bay or lagoon. To establish optimum locations it is first necessary to identify the relevant production criterion for the particular mariculture activity. Table 7.9 shows production criteria established by Cordell and Nolte (1988) which might control the mariculture of oysters. It is then necessary to draw up maps for each of production criterion, showing the spatial disposition of them in a way which can be interpreted as being from "ideal"

Table 7.9 Production Criteria Controlling the Mariculture of Oysters

a)	Proximity of water and shoreline.
b)	Water depth at low tide.
c)	Protection from excessive wave action.
d)	Existence of stream mouths.
e)	Proximity to potential or actual landslide areas.
f)	Electric power availability.
g)	Road access.
h)	Boat access.
i)	Communications.
j)	Proximity to markets.
k)	Proximity to labour.
l)	Upland use.
m)	Water use.
n)	Water temperature - summer and winter.
o)	Salinity - summer and winter.
p)	Dissolved oxygen.
q)	Currents.
r)	Circulation.
s)	Protection.
t)	Predators.
u)	Pollution.
v)	Freshwater.
w)	Phytoplankton concentration.

to "impossible". So, for instance, the depth of water for the mooring of sea cages is an important mariculture production criteria. A bathymetry map can be obtained or drawn up for any area under consideration. Areas of the sea lying at certain submarine contour depths can then be delimited as being, for instance, "ideal", or "good", or "fair", or "poor", or perhaps "impossible". Once all the maps have been drawn up in this way, then a GIS is an invaluable tool which allows the various mapped criteria to be overlayed (or superimposed) so as to collate all the data and to allow optimum locations to be established. Various studies using this type of methodology for aquaculture location have been attempted, e.g. Mooneyhan (1985), Meaden (1987), Kapetsky (1989), Kapetsky et al (1988), Kapetsky et al (1990), Ali et al (1991) and Kapetsky (1994).

A second way in which GIS could usefully be used for mariculture purposes, is in monitoring the effects that mariculture might have on the local environment. A number of studies have shown that cage production has the potential for degrading the environment in various ways (Fernandez-Pato, 1989; Beveridge and Ross, 1991; Pollnac, 1992; Pillay, 1992; Earll et al, 1992; Cook and Black, 1993). Thus Pillay (1992), in a very detailed analysis, shows the following environmental impacts (Table 7.10).

Table 7.10 Possible Environmental Impacts from Aquacultural Activities

* Conflict with other users - for land and water.
* Sedimentation and the obstruction of water flows.
* Effluent discharges - mostly waste feed and faeces.
* Hypernutrification and eutrophication of water.
* Chemical residues.
* Introduction of exotic species.
* Transmission of diseases.
* Loss of local biodiversity.
* Encouragement of predators.
* Danger of hybridization and reduced genetic diversity.
* Creation of mono-scenery.

The use of GIS in terrestrial environmental planning is already well established, and its adoption for monitoring and managing mariculture could follow similar methodologies. Thus, for instance, one of the major problems for cage culture is the excessive build up of undesirable detritus underneath cages. The use of GIS would allow for spatial records of this to be kept, for nearby alternative mooring sites to be located (probably on a rotating basis), and for a study of the relationships between detrital build up and other water or benthic parameters.

A further way in which GIS could usefully be applied is in comparability studies. It is in everyone's interest to have records which compare the success of different enterprises operating either under different conditions or in different locations. This is especially true for activities which have production criteria which are highly variable in the spatial domain. So, if some mariculture facilities are being more successful than others, then it is likely to be for reasons

relating to variable production criteria inputs. GIS is an excellent tool to reveal this. This factor is likely to be increasingly important in the near future, i.e. with the pressures on the availability of sheltered marine space. Then there will be a move towards the greater use of deep ocean moored cages. Sites for these will need to be carefully chosen and entrepreneurs will wish to monitor their financial viability with some care.

Finally, GIS is presently seen as an aid to the development of mariculture but will be increasingly used as a tool for its management.

7.3.7 GIS and the Coastal Zone

Before we investigate parameters relating to the use of GIS for managing the coastal zone, it is important to gain a definition, or at least guidelines, on what is meant by the coastal zone. Several authors have noted the difficulty of precisely defining this (Carter, 1988; Sorensen and McCreary, 1990; Jefferies-Harris, 1992; Kam, 1992), though some facets are obvious. Firstly, there must be a land/sea interface along which there will almost certainly be some degree of marine influences on the land and terrestrial influences on the sea. Thus we would expect to include an element of both land and water into our database parameters. The width of this zone must be variable, but it will usually accord to the strengths of these two way influences. Secondly, the coastal zone must have at least 2.5-D in the sense that coastal waters will have depth, and the shoreline must have some height. Thirdly, there will be both natural and completely artificial shorelines and hinterlands, the extent of which usually accords with a measure of human population density. Carter (1988) and Clark (1992) give illustrations of the different ways in which the coastal zone has been interpreted by various authorities. From a practical viewpoint, the actual definition of the coastal zone which is finally decided upon will be a reflection of the specific purpose to which the marine GIS is being used.

As with the database area of mariculture, at first sight there may appear to be little direct link between a marine fisheries GIS and the database area concerned with coastal zones. However, there are several reasons why this subject area needs some notification. The vast majority of marine species spend at least part of their life cycle in the shallow coastal shelf waters. This period may be for spawning purposes, it may be in occupying nursery grounds or, more frequently, it is for general feeding purposes. So inshore waters play a significant role in species developmental, and as such their existing ecosystems well-being is of profound importance. Given that there were no anthropogenic impacts on the coastal region, then these coastal inshore ecosystems would be able to maintain a self regulating equilibrium i.e. where perhaps long term changes were slowly occurring but where short term variations would be substantially in balance. Although this equilibrium is undoubtedly still able to be maintained, i.e. to a greater degree in perhaps 50% of the worlds coastal waters; in the other 50% varying degrees of degradation are taking place. The critical coastal zone systems which are threatened, and which play a significant role in marine species ecology are listed in Table 7.11.

Table 7.11 **Critical Coastal Zone Systems Important to Fisheries**

* Mangrove forests.
* Coral reefs.
* Submerged seagrass meadows and kelp beds.
* Lagoons and embayments.
* Estuaries.
* Intertidal marshland and mudflats.
* Beaches and wave cut platforms

Degradation is a direct result mostly of human activity along the coastal zone. There are a wide range of possible "negative" human activities, some of which are shown in Table 7.12. Obviously there will be enormous spatial and temporal variations in the extent and degree of any of these activities. Nevertheless, as human populations increase, then the impacts become progressively worse, and coastal waters are now quite rapidly becoming less suitable habitats for most species. One factor which has exacerbated this deteriorating situation is the fact that so many of the human activities shown have taken place, for management and jurisdictional purposes, under separate governmental sources of authority. This has meant that action to alleviate problems has been diffuse, slow and difficult to organise. de Freese (1991) gives an excellent summary of the problems in getting coastal zone management programs underway. However, now that the environmental and ecologic situation is so bad in many areas, joint remedial action is starting to materialise, as is the desirability of managing the coastal zone as a complete integrated ecosystem and/or unit of management (Clark, 1992). It is in both the government's and fisheries manager's interest to investigate any causal reasons and links in the interactions which take place between the various sources of coastal zone pressure.

Table 7.12 **Examples of Human Activities Which May Negatively Impact on the Coastal Zone**

* Exploitation of offshore oil and gas deposits.
* Extraction of sand and gravel aggregates.
* Deforestation of coastal timber resources.
* Water based recreation activities.
* Marine disposal of various wastes and sewage effluents.
* Growth in the desire for coastal urban residence.
* Sedimentation from various land based activities.
* Recreational angling.
* Port activities and vessels using coastal waters.
* Development of mariculture activities.
* Establishment of coastal based industry and infrastructure.
* Destruction of coral reefs.
* Drainage of coastal wetlands.
* Intensification of land-based recreational activities.
* Construction of coastal protection schemes.

* The damming of major rivers.
* Land filling to provide more real estate.
* The dredging of navigation channels.

As well as the fact that the ecosystems quality of coastal waters are increasingly influenced by inshore and onshore human activities, there is another reason why this is an important area for study. There has been a great deal of publicity over the last decade concerning global warming and subsequent sea level rises (see Woodworth, 1993 for a summary of this). Although there has been some debate about definitive causes and effects of this, the results of sea level rise will have profound effects on coastal regions and on fisheries potential. Bigford (1991) gives a useful summary of the fisheries related effects, noting likely changes in habitats, species distributions and fishery yields. It is also important to mention briefly that the coastal zone is particularly threatened by both man-made disasters, such as oil-tankers running aground, and by natural hazards such as hurricanes, tsunamis and storm surges. Because of this, many governments and other authorities have seen that there is an urgent need to manage coastal developments, and worldwide there are many initiatives, e.g. see Crawford (1992), Grip (1992), Halliday and Smith (1992), Suarez de Vivero (1992),

Any database which is established on facets concerned with the coastal zone will inevitably be enormously complex in its range of data holdings. The reason for this relates not only to the fact that the sea/land interface includes an enormous number of varied natural environments, but also because the range of human activities here is large, and this has given rise to a multiplicity of land use types. Another reason for complexity is the necessity of collecting data at a variety of temporal and spatial scales. Thus, not only will factors such as actual land use variety and its rate of spatial variability be varied, but so will the scale of the processes which are occurring. For instance, some coastal areas may be geomorphologically static and change will be slow, whereas in other areas very rapid rates of erosion and deposition are occurring over micro or macro areas. Obviously human generated processes, e.g. marina developments, mangrove clearance and beach resort development, can lead to very rapid spatial changes, which again will occur at a variety of scales. Despite these complexities, there have been attempts at defining suitable database areas for the collection of coastal related information and data. Thus, Figure 7.29 gives an example, taken from Riddell (1992), which gives a strong suggestion as to the types of data which need to be procured. In view of the data complexities, we cannot realistically attempt to suggest data sources on coastal zones and their management, except to mention that many of the sources suggested in Chapter 3 may be relevant, and additional useful information is given by Bartlett (1994).

Unlike the other potential database areas for a marine fisheries GIS, i.e. those discussed in sections 7.3 to 7.8, there has already been a significant amount of coastal zone mapping undertaken using GIS techniques and facilities. We can give a brief resume of some of the work here and some more detailed accounts are presented as case studies in Chapter 9. We can also draw attention to the recent publication by Bartlett (1994) which specifically outlines the impact that GIS has had on coastal zone studies.

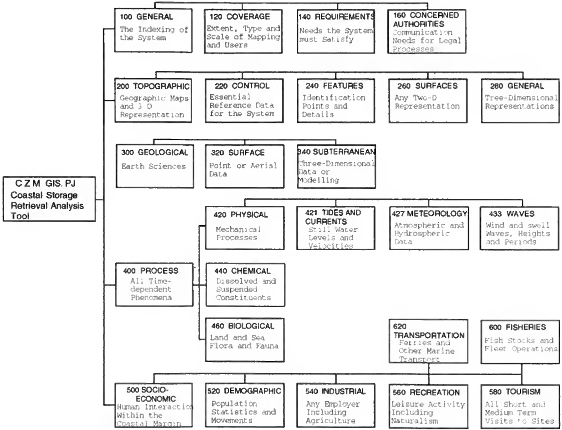


Figure 7.29 **Structure of a Coastal Zone Management GIS Giving Ideas of Database Areas (from Riddell, 1992)**

In an interesting study which looks generally at the use of various mapping techniques that have been utilised for the purposes of coastal planning, Cendrero (1989) gives a range of examples from different parts of the world. Most of them are fairly complex choropleth maps showing land use detail, and they are accompanied by keys which typically show land use classifications or morphological features. An interesting early example of a "GIS" based map is shown in Figure 7.30. Here a number of spatially variable criteria have been combined, and then weighted, in order to produce a "map" showing the suitability of a coastal area in north east Spain to be designated as a natural park. Class 5 on the map is most suitable; 1 is least suitable. A simple programme was written so that the necessary calculations could be made, and the output from the programme was then "mapped" directly to the VDU, from where hardcopy could be printed.

The symbols correspond to the following classes.

Classes	0	1	2	3	4	3	E
		..	000	●●●	ØØØ	•••	
		.	000	●●●	ØØØ	•••	
			000	●●●	ØØØ	•••	
Frequency	6	170	98	363	37	84	E

Figure 7.30 "Map" Showing the Suitability of Parts of North East Spain to be Designated as a Natural Park (from Cendrero, 1989)

There has been tremendous developmental pressure on some of the remaining saltmarsh islands along the east coast of the USA. Preservation of the marshland, and other aquatic ecosystems, here requires detailed and current information on all those factors shown in Figure 7.31. Welch et al (1992) integrated the use of remote sensing, GPS and GIS techniques to produce accurate digital databases on these parameters. Using a series of RS images, plus other hardcopy data, they were able to use GIS functionality to accurately plot land use changes on one particular island, and to measure the rate of logging, the rate of wildlife habitat loss and to measure changes in the size of the island.

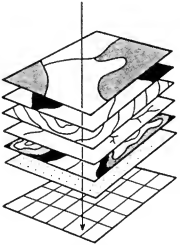


Figure 7.31 Sample Layers used in the Sapelo Island Integrated Resource Database (from Welch et al, 1992)

There has been a large amount of coastal zone mapping and GIS work done by a group of Dutch and German workers covering various parameters associated with the Wadden Sea, which lies along the northern coasts of Holland and western Germany, e.g. Dijkema (1991), Schauser et al (1992), Liebig (1994a). Much of this work has involved setting up a large and complex database - the Wadden Sea Information System (WATIS), which operates in connection with another database - the central Wadden Sea Data Base (WADABA). Much of the output from these databases has been in the form of complex modelling of factors such as wave height predictions, sediment transfer routes, current trajectories plus various tidal models. To visually display what is happening along the coast here, ARC/INFO GIS has been used, and one example of the type of GIS output obtained is shown in Figure 7.32. Other examples of this work are shown in Figures 5.9 and 9.6. Although these Figures exemplify water based parameters, other work has been connected with studying human based pressures on the fragile coastal ecologies, plus work on the biological sensitivity of mudflat areas to human intrusion.

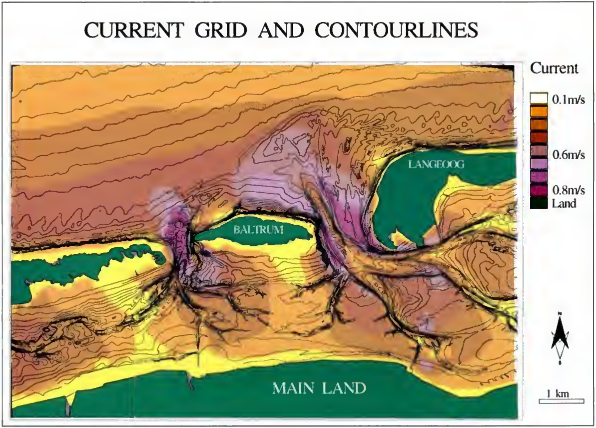


Figure 7.32 Currents and Bathymetric Contours in Part of the German Wadden Sea Coastal Area (from Liebig, 1994b)

CHAPTER 8 - THE IMPLEMENTATION CONSIDERATIONS FOR A MARINE FISHERIES GIS

8.1 Introduction

In introducing this topic it is important to first re-emphasise the actual purposes for which it is envisaged that a marine fisheries GIS be used. What we will be considering here is the implementation of a GIS for the management of marine fisheries, usually by a government department which may be functioning at any level from local to international. If a marine fisheries GIS was being introduced by perhaps a private fisheries industry, a University Department or a Marine Research Institute, then implementation considerations may be very different, though clearly there would be some overlap. Even the implementation by differing levels of government will necessitate different considerations, though these will relate mostly to the scale of the operation and to the scope of the fisheries coverage envisaged. Figure 8.1 sets out the main implementation processes as we see them, plus those responsible for activating them, and we have ordered this chapter according to the systems boxes shown. Since the scope of this topic is so broad, and liable to so much variation from circumstance to circumstance, then our coverage here must be generalised. For readers wishing to know more on implementation considerations, then we would recommend Aranoff (1989), Antenucci et al (1991), Bernhardsen (1992), Korte (1992), CCTA (1993), Walters and Reeves (1993), Hart and Tulip (1994), Huxhold and Levinsohn (1995) or the various "Association of Geographic Information Yearbooks" (1989 to 1995), or the various "International GIS Sourcebooks" which are also published annually.

GIS's are not systems which can be bought "off the shelf" so as to become instant working aids. From the content of previous chapters, it should be recognised that a GIS is an assemblage of items which need to be brought together in a user defined way. Because the acquisition may be a complex process based on a long life cycle, like other business decisions it requires prudent planning and management. A large number of GIS's have failed, or have never come to full fruition, because their implementation was rushed, with the necessary in-depth considerations not being carried out. In a recent study Campbell and Masser (1993) found that the main criteria needed for a successful GIS implementation were:

(i) That there should be a high computing skills level among the staff in the organisation.
(ii) That the organisation should have an innovative environment.
(iii) That initial GIS applications should be simple, and that output which can be seen to be important to the organisation should soon be produced.
(iv) An awareness of the limitations of the organisation in terms of the range of available resources.
(v) Careful management of the projects so that all GIS workers can be seen to have participated in any success.

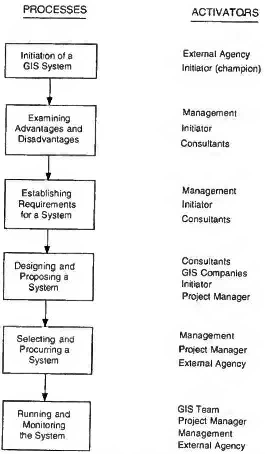


Figure 8.1 **The Main Processes and Activators Involved in Implementing a Marine Fisheries GIS**

(vi) A stable organisational context should prevail within the department, or there should be the ability to easily cope with change.

(vii) A high level of commitment to the goals of the GIS tasks.

A further introductory point of some importance concerns the problem of GIS introduction into some developing country's scenarios. The FAO now has a range of experience in GIS implementation, and in this context some of the constraints (and benefits) of developing a GIS approach to marine resources management in developing countries has been set out by Do Chi and Taconet (1994). This problem has also been carefully studied by Taylor (1991), who has stated, in an introduction to GIS and developing nations:

> "...although GIS has potential to be of utility in the struggle for development, that potential has not yet been realised and there are many problems to be overcome. Some of the problems are technical in nature but the bulk of them are social, economic and political. It is argued that the current developments in GIS are primarily technology-driven and that such an approach has limited relevance to the problems of development in the countries of Africa, Asia and Latin America. GIS....is an artefact of industrial and post-industrial society. Its structures, technologies and applications are products of the needs of these societies. If it is to be used in the context of development then it must be introduced, developed, modified and controlled by indigenous people who understand the social, economic and political context of the situation as well as the technical capabilities of GIS. This may involve some quite different GIS configurations and solutions from those already successful in the developed nations." (p.71)

Taylor goes on to review a range of examples of GIS's which are operating in the developing world and finds that, although a large number of them are achieving varying degrees of success, they are all based upon initiatives from first world agencies or corporations, and in the main they are being led by personnel from the developed world. He doubts that local GIS initiatives will be successfully achieved until there is "socio-economic command of the development of science and technology". The reality "on the ground" in many developing countries is that there is a huge range of priorities which must compete for extremely limited budgets. In this situation GIS is seldom perceived as being important. It may indeed be a distraction on the way to the next meal!

8.2 The GIS Implementation Procedures

Although Figure 8.1 sets out the implementation procedures that we will be following in this Technical Paper, it is important to state that implementation can be viewed in different ways or in different degrees of detail. For instance, a useful way of envisaging the GIS implementation strategy has been proposed by Marble (1994). As Figure 8.2 shows, the development of a particular GIS can be seen to best equate with a spiral of processes and procedures. The "initial model" is achieved by acquiring information, analysing it and then organising it so as to establish the feasibility of the GIS. If the project is then seen as being feasible, another circle of the spiral is gone through in order to create a complete description of what the GIS is to do (the conceptual model). Here the initiator would have worked out factors such as who would be using the GIS, what type of output was required, and how the databases were to be structured. The third loop of the spiral requires that a detailed model for implementation has been devised, i.e. the exact GIS software would be selected, plus specific hardware pieces, staffing needs, etc.

Only after these three spirals had been successfully achieved can the systems implementation really be completed. All the facets of this implementation model can still be performed within the implementation procedures which we outline below.

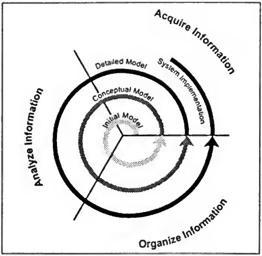


Figure 8.2 Marble's Spiral Model for the Design of a GIS

A second, less abstract way of viewing the necessary GIS implementation procedures, is set out by Antenuci et al (1991) (see Table 8.1). Here implementation is viewed as occurring in five main stages, which are subdivided into 17 steps. Whilst we agree that it is important that all of these steps should be considered, the ordering of the steps could be subject to considerable variation according to local circumstances. For instance, during the whole of the implementation procedure it is likely that there would be "feedback loops", i.e. the necessity to go back to a previous step following a learning process from a current step. Steps such as "system acquisition" might be placed further down the list, i.e. possibly after "site preparation". Also, depending upon systems design, many of the steps could either be carried out "in house", or be carried out externally by a sub-contractor.

Table 8.1 Steps Which Might be Necessary for the Successful Implementation of a GIS (after Antenuci, 1991)

STAGE		STEP
1. Concept	i.	Requirement analysis.
	ii.	Feasibility evaluation.
2. Design	iii.	Implementation plans.
	iv.	Systems design.
	v.	Database design.
3. Development	vi.	System acquisition
	vii.	Database acquisition.
	viii.	Organization, staffing, training.
	ix.	Operating procedure preparation.
	x.	Site preparation.
4. Operation	xi.	Systems installation.
	xii.	Pilot project.
	xiii.	Data conversion.
	xiv.	Applications development.
	xv.	Conversion to automated operations.
5. Audit	xvi.	Systems review.
	xvii.	Systems expansion.

8.2.1 Systems Initiation

The original idea to proceed with the adoption of an innovation such as GIS, may not have come from within an organisation, i.e. it might have been suggested from outside by a consultant or an aid organisation, or it might have been imposed by perhaps a parent company or by someone who has seen its success elsewhere. Alternatively, the GIS implementation idea may have come from within an organisation by an employee who has perhaps read about its potential, and who is keen to see a GIS adopted. By whatever means the innovation was first conceived, as with the inception of many new ideas, to make sure that its adoption is successfully it almost inevitably will require action by someone with what might be termed a "visionary or imaginative spirit". This individual has been called the "champion" or the "initiator". Clearly the person will need to be in the position of having complete understanding of all the prerequisites for success. He or she could be someone working at more or less any level in the organisation, as long as they have sufficient time to nurture the project implementation. The person will also need to have a very good idea of the potential which a fisheries GIS will have to offer.

It is vitally important to have, or to gain, the support for the implementation from any senior management who might be in some way involved. The "initiator" will usually be the person who will take the responsibility for advancing the GIS adoption plans through the various stages shown in Figure 8.1, although they, or the fisheries management, might decide that it is necessary to appoint a project planner. Whoever undertakes the task, the person will need the necessary degree of independence and authority to ensure that each phase can be activated in a potentially successful way.

One way in which the "initiator" can promote the idea for GIS adoption is through the organisation of internal or departmental seminars. These need to be well organised, using if possible external expertise to put over the more technical aspects of implementation, and to give a visual, illustrative idea of the capabilities of GIS. These seminars should also consider the repercussions of GIS implementation on the fisheries department and its current practices, and they should conclude by underlining the next implementation steps which would be necessary.

8.2.2 Advantages and Disadvantages of Introducing a GIS

The aim of this Technical Paper is primarily to provide information concerning the application of GIS to various marine fisheries tasks, and there will be many readers who will be investigating the possibility of such an implementation. Clearly, before entering a commitment into what is a complex and broad ranging technology, it is sensible to find out as much as possible about what may be involved. A traditional way of deciding upon the utility of a proposed innovation, is to carry out a cost-benefit analysis. To do this in the case of most GIS's is usually difficult. Although a fair indication of the costs can be derived (with the exception of data costs), the benefits are far more difficult to calculate since in the main they are either very long term and they may be intangible, i.e. typically they represent additional or improved means of assessing spatially related considerations, or other considerations to which monetary values do not apply. Though various authorities in the past have given benefit/cost ratios, usually in the range of 2:1 to 4:1, the length of time over which these benefits accrue will vary enormously.

As an alternative to using cost-benefit analysis, it is frequently more rewarding to simply examine the advantages and disadvantages of acquiring a GIS from the viewpoint of a potential user, i.e. rather than from somebody who is within the GIS industry and who would therefore see GIS in a completely different light. Finding out any advantages and disadvantages must be an important initial task for the "initiator". Although we include here an analysis of the advantages and disadvantages of GIS near the beginning of the implementation procedures, we recognise that a consideration of these might be revisited after a systems requirement analysis had been undertaken (section 8.3.2). What follows is a listing, in no particular order, of firstly the main benefits of GIS, and then the main problems (costs or disadvantages) which may be encountered.

8.2.2.1 The Benefits of GIS

* GIS can allow for an advance from straight forward and traditional descriptive mapping, to prescriptive mapping.
* Once maps have been established in a digital format, then it is a simple task to update them, to change them, or to merge them with other maps in order to create new maps.
* GIS provides a huge range of tools which allow for accuracy of output and thoroughness of decision making.
* The range of potential graphic displays is almost infinite, allowing maps to be customised to suit situations and individuals or tasks, and allowing for visualisation experiments to take place.
* GIS contains the prerequisites for modelling scenarios, both from the research aspect and in operational resource management tasks. Multiple scenarios can be rapidly undertaken, and varying hypotheses can be tested.
* GIS allows for the easy and immediate integration of other large data sets, i.e. the technologies of, for instance, GIS and remote sensing or GIS and acoustic SONAR imagery, can be readily combined.
* GIS allows for the display of spatially related data in a way which is easily comprehensible to most people.
* The use of GIS greatly improves human productivity and the speed of working in all map producing operations.
* GIS allows for a regular flow of spatially related information in a standardised format. This might be for a given time series where all maps are produced together, or it might mean that periodically a new version of the same map can be produced.
* GIS allows for the production of one-off maps of a high quality, which would otherwise be non cost effective.
* GIS allows for high quality cartographic output from people who might have no cartographic skills.

8.2.2.2 The Disadvantages of GIS

* GIS implementation will undoubtedly have an impact upon the department, such that organisational changes will be necessary. There could well be "losers" in this process.
* The cost of data inputs will inevitably be high, either in terms of purchasing existing digital data, in carrying out digitising, or in setting up and maintaining data gathering systems. These costs could be unpredictable at an early stage. So the actual value of utilising a GIS is difficult to establish.
* The input sources to a GIS may be of a varying standard. This means that a certain degree of error propagation will be inevitable and the extent of this is difficult to measure.
* The means and degree of access to data sources will be variable. The legal position with regard to this is sometimes poorly determined or unnecessarily restrictive. There are copyright problems in making newly created data available.

* There is still a huge problem with explaining and describing the potential that a GIS has to offer. This is due to the intangible nature of the advantages, the fact that the system is quite complex, and the difficulty in many areas of acquiring the systems' prerequisites.
* Advances are being made in the general field of GIS which occur too rapidly for the average worker to keep up with, and which cause the rate of systems obsolescence to be very high.
* As yet there are still no universal standards for GIS data, i.e. for allowing the easy transfer of data between countries and systems.
* "User friendly" interfaces have been slow to materialise in GIS software, and some systems still rely on the knowledge of a complex command language. Much of the documentation could be described as "formidable".
* There is still no easy way of finding out exactly what databases are in existence or what the rules of accessibility are.

8.2.3 Systems Requirement Analysis

For the GIS to be successful, it has to meet with the expectations of a variety of groups. These might include:

(a) The "initiator". He or she will clearly have expectations of what is possible from the system and, since this person will have the greatest hopes of success, then he or she might prove the most difficult person to satisfy in terms of GIS operation and of output.
(b) The fisheries management. They will have been told that the GIS is capable of producing a range of output which is going to make their job easier. They will therefore be expecting "results", and these might be required within some sort of hierarchical time scale, and to a certain level of clarity.
(c) The GIS operating team. This team may have quite a different make up from department to department, which usually accords with the scale of the GIS operation. Whatever its size, it will have expectations of the system in terms of not only meeting any output requirements, but also of the system's ease of use, its "user-friendliness", and in terms of its future potential and job opportunities.

If all of the groups are to be satisfied, then a great deal of initial investigation is necessary. It is this investigation which makes up the systems requirement analysis (sometimes referred to as a feasibility study - or the "initial model" in Fig 8.2); it is important to differentiate between this and the next phase of the implementation, i.e. the systems design and proposals. The former, which is described in this section, is essentially concerned with identifying what it is that the GIS is going to be required to do, whilst the latter is concerned with how the GIS will be set up to perform any identified tasks. The systems requirement analysis itself must be conducted by staff and/or external consultants who understand most aspects of fisheries or aquaculture, and who are also aware of the full potential of GIS.

Obviously the first task, if it has not already been done, will be to explain to the requisite fisheries managers exactly what a GIS is and what it is capable of doing. This task itself might

come in response to needs which have already been identified, or it might come in the form of suggestions from the "initiator", or from an outside agency such as the FAO. It could be envisaged, for instance, that the fishery manager has identified a spatially related need such as "How much fishing effort is being put into sector x during the summer season?" or "Why is area y failing to produce fish in the quantities that it did last year?". Equally, it could be envisaged that the fisheries manager will have no idea of the existence of GIS and therefore of its capabilities. It will then be in the initiator's (or outside agency's) interest to outline these possibilities, using examples where possible. For some larger GIS installations, then this is the point where a pilot project could be carried out in order to demonstrate the potential for GIS in a selected field. This might also be the time to review the experience which other companies or departments have had in setting up their own GIS's. All systems implementations will have experienced problems and will have found out "useful tips". If possible, learn directly from others who have been "hands-on" users in other firms.

As a result of finding out the possibilities, it will be important for the fisheries managers, in conjunction with the "initiator" or an external consultant, to decide upon the range of functions and the spatial area(s) that they wish the GIS to initially cover, and the range that they hope will eventually be covered within a reasonable time scale. The scope of this could vary enormously, from perhaps a full fisheries management project covering an entire region, such as the Regional Maritime Database (BDRM) of the "Ministerial Conference on Fisheries Cooperation Between the African States Bordering the Atlantic Ocean", and its fisheries GIS component (Anon, 1993b), to a project which might only cover one small geographic area or fishery topic. Finding out the range of functions required for the GIS might be undertaken via a user needs survey, or through some form of multi-lateral discussions. It is important here to stress that whatever GIS output is required, it will only be obtained sequentially, i.e. there must be no expectations of a large array of output all being produced simultaneously by some given date. In our experience it is best to commence the introduction of GIS with a limited set of realistic goals. Since the number of processes to be gone through between establishing the goals for any GIS and actually obtaining them are so many, then it is important that the management realise that time scales for any output may need to be flexible.

The main factors influencing the GIS goals which are first chosen may not only be related to management requirements, i.e. they may also have to relate to the ease of achieving an output goal. Thus, for any goal, data will be required, and it is initially important to set initial goals for the GIS which relate to realistic data availability, plus the capability of achieving output from any early configuration of the total GIS set-up. It is also important to keep a track on any perceived eventual GIS goals so that there is always a target to be aiming for.

So one of the major tasks in the systems requirement analysis will be to seek out the availability of useful data, and to establish some form of data inventory - the beginnings of a meta database. Since this is such a time consuming task, it is going to have to be undertaken at an early stage and with a large degree of manual input. In Chapters 2 and 3 the whole of the data collection strategies were discussed in some detail. It will inevitably be found that some of the data needed does not exist in the requisite form, or does not exist at all, so a major part of the requirements

analysis will be to work out any data gathering systems which may need to be put into place. There may be a case for further searching for existing data, or for ways of modifying existing data, or more frequently it will be necessary to establish how new data is to be secured.

The range of GIS output which is required in the foreseeable future will play a large part in determining the scale of the GIS in terms of both the system's size and its capability, and consequently in the financial and personnel investments which will be necessary. Again, we would advise in thinking comparatively small at first, and then in letting the GIS developments gradually evolve through the increased familiarity by all involved. We can confidently recommend this approach, since the physical costs of investments in the system at the start-up stage can now be very low indeed. Thus, in Chapter 5, we indicated that all the basics for a realistic fisheries management GIS, operating at a start-up level, could be purchased for less than US$5 000.

A further systems requirement factor which may be of importance relates to who the users of the GIS are going to be, or which department needs to be physically connected to the system when it is established. If the GIS is envisaged as simply operating as one small unit within perhaps a small fisheries department, or within one specified sector of a larger department, then this may not prove to be much of a consideration. However, it is more likely that the fisheries department itself is split between different physical sites, each of whom may wish to be involved with the GIS, or that the fisheries department wishes to be integrated to some other allied department or organisation, e.g. perhaps a department concerned with environmental management. In this case decisions will need to be made on the best siting for the GIS and what physical connections are desirable. Similarly, for a variety of security reasons, it will be necessary to decide on exactly who, or which departments, should be allowed access to the GIS.

At the end of the systems requirement procedure, it might well be decided that the fisheries department (or facets of the fisheries management) is not yet at a stage where it is ready to incorporate any GIS work into its activities. In this case GIS implementation may be abandoned, at least for the present. However, if this is the case, it would be as well to consider that a GIS might be taken up at a later date. Bearing this in mind, if any data collection systems are being put into place, then it is vital that they consider the incorporation of geo-referenced recording. It might also be the case that only a small amount of GIS work was found to be necessary, i.e. such that it was not worth the effort of setting up an internally operated system. In this case consideration should be given to contracting out the work to an external organisation. Obviously, the "pros and cons" of doing this will need careful consideration, and a consultant should be able to advise on this.

8.2.4 Systems Design and Implementation Proposals

Having established exactly what the requirements of the GIS are, then it is essential to work out in detail an overall systems design, and to put this together as a GIS implementation proposal. This is sometimes called a strategic GIS development plan - or it may equate to the "conceptual model" in Figure 8.2. The main points for doing this are that it is clear in the mind of all the

involved fisheries department personnel what the full extent of the plans are, and also that the implementors of the GIS know what is to be expected from the system. The strategic plan should be phrased mainly in terms of the output needed from the GIS rather than in any technical terms of how the system might operate. The plan will need to incorporate a degree of flexibility since, during the whole implementation stage, which for a complex system could last for two years, then there are certain to be many changes. Despite the timing uncertainties, it is useful to timetable approximate target dates by which all parts of the system should be in place and functioning.

With regard to GIS systems design, then it is difficult for us to give specific advice since it will be different in almost every situation. What we can usefully do however, is to propose a series of questions, covering four main areas of GIS implementation which need to be considered. The areas are: (i) hardware, (ii) software, (iii) total systems and (iv) personnel. The answers to these questions should be sought in conjunction with someone who is familiar with the requirements of the fisheries GIS such as the "initiator", a project manager or with a GIS consultant. As well as these major areas, considerations will need to be given to all the other factors listed in Table 8.2.

Table 8.2 The Major Factors Which Should be Included in a GIS Implementation Plan

* The location for a GIS.
* Hardware needs.
* Software needs.
* Systems configuration.
* Personnel needs.
* Training provision.
* Data acquisition, structuring and storage procedures.
* Database design.
* Future data flow patterns.
* Maintenance of the databases.
* How to maintain quality of inputs and outputs.
* Overall systems management.
* Recommendations about a pilot study (if needed).
* Listing of all functions to be automated.
* Time schedules and milestones for the various activities.
* An investment plan and budget, including insurance and depreciation.
* Any restructuring of the organisation which might be necessary.
* The geographic areas which the GIS will cover.
* The subject areas which the GIS will cover.
* The allocation of physical space for the GIS.

8.2.4.1 Some Hardware Implementation Considerations

Details on the various hardware components have been outlined in section 5.2. In making purchases (or leasing) any hardware, the main questions to consider are:

* What types of peripherals are required, e.g. pens for plotters. Are these peripherals readily available?
* What sort of maintenance agreements or guarantees exist? How much are servicing costs? What might be the expected quality of the back-up received?
* How user friendly is the prospective item? This includes both how easy is the item to use and are the manuals to understand.
* Where might the purchase best be made? Can I get independent advice on this?
* Given that the obsolescence rate on equipment is very rapid, i.e. an average of five years, are there any new models about to appear?
* What are the relative merits between various, but similar, pieces of equipment? How can this best be evaluated?
* Will the equipment be compatible with the rest of the system? How flexible or extendable is it?
* What quality, quantity, size, colour and range of output is required?
* How many users are likely to require access to the hardware and might this access be at the same time?
* How often might the hardware be used?
* What is the throughput requirement from each piece of hardware? This may be especially relevant to printing and plotting devices.

Clearly it would be possible to mention a range of lesser considerations, but these are the important ones relating directly to hardware acquisition. It is also important to mention that there is no "right" hardware to buy. What is decided upon will reflect personal preference, software choices, finance available, functional requirements, the degree of interaction with other systems, etc.

8.2.4.2 Some Software Implementation Considerations

It is initially important to remember when selecting software, that there is unlikely to be one single GIS software package that will perform all the user requirements. This makes it inevitable that the software choice will be made in terms of selecting a suitable package which best performs a range of specified tasks. Further details on software were given in section 5.4. Some of the main questions which need to be asked include:

* Is it important whether or not the software is raster or vector based? Is it essential to have both capabilities?
* Which specific GIS software can best form the centre of the complete GIS?
* Since most software is now being marketed as a series of modules, which modules will it be important to buy?

* Can the software produce the necessary range of data manipulations and final output which is required?
* How much flexibility does the software have in terms of presentational output? Can the user design their own symbols and other presentational features?
* What operating systems will it be necessary to acquire? Are there facilities for communicating with other systems?
* Will extra database management packages be needed? If so which ones will best integrate to other software components?
* How user friendly is the software? Does it have a fully integrated menu system? How easy is this to understand?
* What support is given for the software? Are there telephone help lines? What degree of commitment to the user seems possible?
* What is the cost and approximate frequency of software updates? * Is installation performed by the software company? How much does this cost?
* Does the software company offer training facilities?
* How "open" is the software, i.e. can it easily be integrated with other software, including communications programs?
* How well does the GIS software perform on various types of hardware or hardware combinations? What might be the optimum hardware platforms for a particular package?
* What is the user instruction and system support documentation like?
* Does the software have facilities for restricting access?
* What are the means for restructuring any databases?

We have not included questions about the reliability of the software company, its reputation, its financial resources, its sales turn-over, etc., but if possible these should be discretely ascertained. Since it is often difficult to chose between one GIS software and another, Bernhardsen (1992) has suggested a way of evaluating between different systems (Figure 8.3). Here a, b, c and d represent four different GIS software packages.

8.2.4.3 Some Configuration Considerations

In this section the questions for consideration are wider than in the previous sections, and they will include both hardware and software, i.e. here we are thinking in terms of the whole GIS as a functional system. Actual variations in configurations were discussed in section 5.3. The main questions to ask are:

* Should we go for a turnkey system? This is where the software company, or sometimes a specialist consultancy, develops a complete GIS package of hard and software, which is delivered to specifications for undertaking prerequisite GIS tasks which the user has set out. This method of GIS purchase is normal where large scale systems are planned. At this stage in the development of fisheries management GIS's, it is doubtful whether the systems requirement are such that specifications could be drawn up, though undoubtedly this will happen in the future.

	weight	rank				weighted rank			
Selection criterion		a	b	c	d	a	b	c	d
System cost	5	7	7	6	9	35	35	30	45
Database design	4	6	7	8	7	24	28	32	28
Man-machine interface	5	8	6	7	6	40	30	35	30
Equipment functionality	3	7	8	7	7	21	24	21	21
Own programming	3	7	5	5	6	21	15	15	18
Follow-up	4	7	6	6	8	28	24	24	32
Data interchange	5	8	7	6	5	40	35	30	35
Expansion possibilities	4	7	8	8	8	28	32	32	32
Documentation	4	7	6	6	5	28	24	24	20
Maintenance costs	4	9	5	6	6	36	20	24	24
Drawing functions	2	7	9	9	6	14	18	18	12
Unweighted sum		80	74	74	73				
Weighted sum		315	225	255	287				
Rank		1	3	4	2				

Figure 8.3 An Evaluation Matrix for Selecting a Suitable GIS Software Package (from Bernhardsen, 1992)

* Are there particular departments who might wish to share in GIS activities, and where would it be beneficial to have direct computer links to? Will these need to be LAN's or WAN's?
* What are going to be the immediate computing systems configuration needs? Where should these be physically housed?
* How easy will it be to increase the system's functionality or to improve its performance? How flexible is the system?
* How will the whole system perform in the case of a power failure? How can the integrity of the system be restored after such a failure?
* What features exist to prevent unauthorised access to the system, or to specific parts of it?
* To what extent will the system be able to utilise any IT components which the department already possesses?
* Will all the data requirements be held in the department's own system, or are there external databases to which linkages must be made?
* Where can independent advice about system's configurations be obtained?
* How can data storage best be arranged? What storage capacity do we need now, or might we need in the near future?

As with considerations of hardware, there will be no correct configuration, and the final choice will depend on a number of factors. It can be guaranteed that nearly every GIS which is presently functioning will be configured in a slightly different way, with the range of possible combinations being almost infinite!

8.2.4.4 Some Personnel Considerations

The implementation of GIS will not happen without personnel being involved. Until a few years ago it was extremely difficult to obtain most categories of GIS trained personnel. However, since various GIS education and training programmes have been functioning over a number of years, then this shortage problem has now been greatly ameliorated, though the situation will obviously vary between regions or countries. In many situations there will already be computing personnel who might be prepared and capable of taking on additional GIS work. It is important to realise that if only one person is allocated to GIS work, then they are likely to have to be very versatile, i.e. in the sense that GIS involves a detailed knowledge of not only computing and the intricacies of the software, but also of spatial analyses and probably matters relating to fisheries as well. The range of personnel skills which might be needed to manage and operate a fisheries department GIS includes systems administrators, GIS analysts, programmers, production personnel, support staff and cartographic technicians.

Implementation considerations regarding personnel require that a varied set of decisions are made and questions are asked:

* How exactly do we break down the GIS oriented tasks? What particular staffing mix do we need? Will it be feasible to allocate tasks fairly around so as to make optimum use of expensive personnel?
* Will it be necessary to hire new specialist workers? If so, how do we approach this task?
* Would it be better to promote people who already work at the fisheries department? How do we select such people?
* How do we train personnel? Is this better done "in house", or should they be sent to an externally organised course?
* For what tasks do we require external people to act as consultants?
* At what level do we need to make appointments?
* How do we define the exact responsibilities for any new posts? How much decision making authority will each individual have?
* How do we best motivate a GIS team?
* Is it important that all employees see the value of GIS?
* Will the GIS implementation lead to personnel redundancies or the need to change job classifications? How should this be handled?

8.2.5 Systems Selection and Procurement

It is difficult to outline this section precisely since the procedures followed are often developed by individual organisations, who therefore have no choice but to follow the company's set of rules. However, certain basic factors should at least be taken into consideration.

Some documentation should have been prepared which sets out clearly, for the benefit of senior management or for any potential GIS suppliers, exactly what the aims of securing any GIS are, what its costs and benefits might be, and how it is envisaged that these aims can be secured in

terms of hardware and software. The document would equate with the "detailed model" in Figure 8.2 and, in reality, it might well take the form of an "Invitation to Tender". This is a document which sets out in detail the requirements of the total GIS, and which can be forwarded to potential GIS suppliers. They can then respond detailing likely costs and timings, and outlining exactly how they might propose to meet your requirements. Any potential systems supplier can be asked to carry out "benchmark testing". Here several software companies are given an appropriate GIS task to perform, and the user can make his decision to purchase depending upon how well the tasks have been executed. We feel that it is unlikely that the application of GIS techniques to marine fisheries is yet at a stage where any very detailed tendering or benchmarking is necessary, though undoubtedly these will be prerequisites in the future.

At this stage in the development of GIS applications to fisheries management, it is most likely that procurement will result from recommendations made by the project planner or by a consultant. They should obviously be in a position to have registered the user needs as outlined above. In practice, the exact nature of the GIS acquired will reflect the local situation in terms of the budget available, the anticipated output scale of the GIS, the present existence of any hardware plus the local availability of any expertise or back-up. Where possible local purchases of software and hardware should be made, since this is where any after sales service will need to come from. If it proves difficult to find out who the local suppliers are, then this can be checked in one of the major GIS trade directories (see section 8.3). The trade directories also provide lists of companies who can advise or help with the complete GIS implementation programme.

8.2.6 Systems Management, Operation and Development

Once a GIS has been successfully installed, there are still a number of tasks to be faced if the system is to continue to function satisfactorily. Thus it is very unlikely that the GIS will be producing any desired output from day 1. There remains a requirement therefore to ensure that the system delivers the benefits that were expected of it. This can best be achieved through undertaking some or all of the following:-

a) Preparing the Organisation. Part of the operations process which often receives insufficient attention is the preparation of the organisation (in this case usually a fisheries department) to receive the new technology. This will involve several important tasks. It is almost inevitable that the development of new working practices will have to take place. This may mean staff having to work to new routines, possibly in new venues and with a different set of duties, responsibilities and targets. For some employees this could cause stress and the necessity for sympathetic attitudes from colleagues and managers. We see it as important to initiate a GIS user group. This might constitute a multidisciplinary team and perhaps other interested parties, some from outside of the department on a part-time basis, usually from different "levels" within an organisation, and usually under the direction of the "initiator". The main function of this group would be to plot and plan progress, to resolve problems and to keep other parties up-to-date with

any progress that the GIS is making. From our experience with GIS implementation, it is of fundamental importance to familiarise other workers in an organisation about any implementation plans including the perceived uses of the GIS and the progress which is being made.

b) Training. Almost all personnel involved in the GIS adoption will require some training, and training requirements will certainly vary between individuals according to their previous experience. For some, perhaps the senior management, training might be simply a brief familiarisation of what GIS is and what its capabilities are. For most others, training will need to be of a more practical nature. In section 8.3 specific training needs are discussed, but here it is important to highlight some operative requirements.

It is essential that at least one member of the GIS team, probably but not necessarily the person in charge or the "initiator" (see section 8.2.1), has an overall working capability with the system. This does not mean that he or she needs to know absolutely everything. There may well be others who know more about certain areas, but it is important that someone has an overall conceptual vision of the entire required set of GIS processes. The reason for this is that, having a holistic view of the GIS processes, enables the best working practices to be established. This person will also be of use when other personnel are absent or when there are other working pressures. It is also important that at least one person has some specialist training in the use of the particular GIS software which is being used. Likewise, training will be needed in the operations of all hardware items. In making allowances for training, the department must be aware that upgrades of the software may be quite frequent, and familiarisation with these will be essential.

c) Management Involvement. It would be impossible for a GIS to be successful without having management support, since presumably the management are the people who know where the organisation or department is headed in terms of development, and since they are the ones who control the budget. This means that not only must the key management have been persuaded that a GIS is capable of bringing benefits to certain aspects of their management, but also that the management should play an active and interested role in fostering the development of the system. Managers should be aware of what is going on and they should be told of advances as they occur. It is only with their enthusiastic support that any future GIS advances will be made.

d) Service and Maintenance. All parts of the delivered system will require some maintenance and hardware should receive regular servicing. When the equipment is purchased then there are usually agreements which can be entered into which cover either or both of these.

e) Monitoring of Progress. Is the system living up to its expectations? It is very useful to have in place some form of GIS auditing procedures under which systems monitoring can be made. These procedures will have to be worked out in advance and may take the form of establishing targets which should be reached. Then auditing will take the form of measuring the extent to which targets have, or have not, been met. It is important that all parts of the GIS operation

have a system for being checked, and that auditing and evaluation is in terms of both monetary and systems output targets. This monitoring will also be essential in planning realistic future GIS targets.

The auditing procedures can be useful in determining when to make changes in the GIS set-up. Thus, any single GIS cannot hope to keep up with all the advances in technology. There must be some stability otherwise users will be constantly working on keeping up with hardware or software version changes, rather than concentrating on actual problems. Planning and monitoring should anticipate future developments, but decisions to change cannot be made with precision, and they should not generally be made until absolutely necessary.

8.3 Guidance and Support for a Marine Fishery Resources GIS

Until a decade ago, GIS was almost unknown. During the late 1980's the subject area began to take off and as the technology proliferated, then so too did all the aids to the technology's success. By 1990 there was already established a number of basic texts in GIS, some trade and academic journals had emerged, conferences had started to become held as annual events where the industry could show itself to those who were interested, various education initiatives had been fostered, and a range of back-up services had begun to emerge. Over the past five years all these facets of support and guidance have become well established, or have proliferated and now a far wider audience is accommodated. GIS is very much main stream in the subject areas of Geography and Information Technology or Computing. In this section it is our intention to provide a few leads as to where further guidance and support can be sought. Once the reader has embarked on this, he will quickly uncover a host of fresh leads. Our main problem in examining this whole area is that guidance and support is now offered on a world wide basis, and we cannot possibly hope to cover more than a very limited number of approaches. These are likely to be biased towards European sources.

8.3.1 Practical Guidance, Education and Training

Under this heading, we propose to examine those sources where some "hands on" experience in GIS can be gained. This will usually mean that the student, tutee, trainee, etc, will need to go to a venue where they will receive some kind of practical GIS tuition. Space will prohibit a consideration of guidance, education and training in all of the peripheral areas and in the hardware which may be allied to GIS. For readers who wish to find out more on general guidance and training, then we recommend Gilmartin and Cowen (1991), Goodchild and Kemp (1990), Green (1992), Gittings et al (1992) and Kemp et al (1992).

One of the problems with obtaining guidance and education in GIS is that the subject requires some knowledge from a wide subject range. Thus any student who is embarking on a GIS course which is of limited duration (say one year or less), invariably goes into it lacking at least some of the essential background knowledge or expertise and, since teaching time is limited, he or she may need to do a range of extra reading or research in order to get sufficient scope of

experience. Added to this there is the problem of learning a range of computing skills and of gaining familiarity with a number of software programmes. So, in practice, very little practical knowledge may be able to be gained from most short GIS courses.

Within higher education establishments GIS tends to be taught in one of several ways. Firstly, a number of postgraduate degree or diploma GIS courses are available. These are usually of one year duration and, since they are often aimed at people who are already in employment, they may take the form of evening or distance learning courses. Most European and North American countries have institutions offering such courses. Secondly, GIS may form a complete unit or module of an undergraduate degree, usually associated with Geography but also with Computer Science courses. Many Universities or Colleges of Higher Education offer such programmes. GIS may also be integrated as one limited component of a an existing geography or computing module. This will be the case where pressure of space in the curriculum, or the lack of computing facilities, causes the teaching to suffer from a resource limitation. Some of the undergraduate courses are now also being offered on a distance learning basis. Finally, an example of a different approach is the type of course which is being put on by the University of Aberdeen, i.e. their B.Sc in Marine Resource Management. This course covers a broad spectrum of topics related to marine resources, but it is special in that the use of GIS (and to a lesser extent remote sensing) pervades all aspects of the course, so that the student finally gains competence in both the relevant theoretical material and also practical computing and GIS experience (Green and Stockdale, 1993). Figure 8.4 gives some idea of the range and number of GIS courses available in the UK.

Another way of obtaining hands on training is through the use of "in-house" exercises or tutorials which are supplied by some of the major software suppliers, or which are specifically written, usually by university departments. For instance, practical work books have been produced by Clark University in the USA to teach GIS through the use of their IDRISI software, by ESRI (Environmental Systems Research Institute) to teach their ARC/INFO software, by Thinkspace to teach their MAPII software, and TYDAC, through its Institution for GIS in Education, has educational teaching materials for its SPANS software. Special tutorial books, which come with supporting disks, lecture notes, exercises, etc, include those by Langford (1993), Strachan et al (1992) and the IDRISI Project (1993). The Dutch company ITC, which produces the GIS software ILWIS, has a large educational programme, supported by various international agencies, which is aimed at introducing GIS to interested workers in the developing world. There are similar initiatives to teach the applications processes relative to image analysis. For instance, an excellent way of learning the basics of remote sensing, as it applies to the marine situation, is through the use of the "MARINF/90" tutorial programme (Robinson et al, 1993), which is produced through UNESCO. These are a set of computer based modules which cover a wide variety of marine RS applications, and they can either be worked through individually, or they could form part of an undergraduate level teaching programme.

There are still other ways of obtaining hands on GIS experience. Some of the Universities and the software houses put on very short courses, i.e. typically of one to three days duration, giving almost no time for practical sessions. These are primarily aimed at people in business who

	BSc	Diploma	Ma	MPhil	MSc	Phd	Post Graduate Diploma	short course	other qualification
Birkbeck College - University of London	–	–	–	–	–	–	–	♦	–
Cambridge University	–	–	–	♦	–	–	–	♦	–
Coventry University	♦	–	–	–	–	–	–	–	–
Cranfield University	♦	–	–	–	♦	–	♦	–	–
East Anglia University	–	–	–	–	♦	–	–	–	–
Glasgow University	–	–	–	♦	♦	–	–	–	–
Keele University	–	♦	–	–	♦	–	–	–	–
Kingston College	♦	–	–	–	–	–	–	–	–
Kingston University	–	–	–	–	–	–	–	♦	♦
Leicester University	–	♦	–	–	♦	–	–	–	–
Liverpool University	–	–	–	–	–	–	–	♦	–
London School of Economics	–	–	–	–	–	–	–	♦	–
Manchester Metropolitan University	–	–	–	–	♦	–	♦	–	–
Portsmouth University	–	–	–	–	♦	–	♦	–	–
Sheffield University	–	–	–	–	–	–	–	♦	–
Stirling University	–	♦	–	–	♦	–	–	–	–
Strathclyde University	–	♦	–	♦	–	–	–	–	–
University College London	–	–	–	–	♦	–	–	–	–
University College of Swansea	♦	–	–	♦	–	♦	–	–	–
University of Aberdeen	♦	–	–	–	♦	–	–	–	–
University of East London	♦	–	–	–	–	–	–	–	–
University of Edinburgh	–	♦	–	–	♦	–	–	–	–
University of Greenwich	♦	–	–	–	♦	–	–	–	–
University of Hertfordshire	–	–	–	–	–	–	–	♦	–
University of Huddersfield	–	–	–	–	♦	–	♦	–	–
University of Leeds	–	♦	♦	♦	♦	♦	–	–	–
University of Luton	♦	–	–	–	–	–	–	–	♦
University of Newcastle upon Tyne	♦	–	–	–	♦	–	–	♦	–
University of Nottingham	–	–	–	–	♦	–	–	–	–
University of Reading	♦	–	–	–	–	–	–	–	–
University of Salford	–	–	–	–	♦	–	♦	–	–
University of Sussex	♦	–	–	–	–	–	–	–	–
University of York	–	–	–	–	♦	–	–	–	–
Wales University	–	♦	–	–	♦	–	–	–	–

Figure 8.4 GIS Courses Available in the UK

require a working knowledge of the functionality of GIS. These courses can be very expensive to attend, though some are put on cheaply (or free) with the ulterior motive of persuading the attendees to purchase the software of the promoting company. Some private companies who may

have strong links with GIS activities, also put on a variety of relevant courses, e.g the Groupement pour le Developpement de la Teledetection Aerospatiale (GDTA) in Toulouse, France, provides an extended range of GIS related courses. Another way of gaining experience, or at least familiarity, is through the use of specifically designed GIS tutorial software. The main product here is GIST, the GIS Tutor produced by Birkbeck College at the University of London (Raper, 1992). GIST was developed in Hypercard for use on Apple Macintosh computers but it is now also available in the Windows environment. Through the "hypertext" concept the user is able to follow through linked concepts along eight main themes (Figure 8.5). There are hundreds of information cards along the theme lines, many of which are animated thereby allowing user interaction with the tutorial package. The tutorial is mouse-driven so that no commands have to be learned. Another GIS training package, GISTARS (Geographic Information STARter System), has been developed by the Pennsylvania State University specifically as a package which can easily be adopted in developing countries. It has an in-built digitising capability, the documentation is self contained, it runs on very basic PC's and it has been field tested in rural India (Myers, 1990).

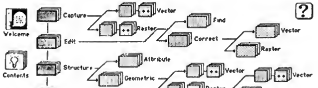


Figure 8.5 A Sample Page from the GIS Tutor Programme

8.3.2 Published Guidance and Information

Academic journals and trade magazines which cater wholly or partly for GIS now appear world-wide. The trade magazines are useful sources for finding out recent GIS developments and applications, as well as for locating suppliers through the advertisements. They also give

complete listings of various GIS services which are available, plus the names and addresses of suppliers and of GIS related organisations. Some of the main GIS related journals and trade magazines (#) are listed in Table 8.3.

Table 8.3 The Main GIS Journals and Trade Magazines

* The Cartographic Journal.
* Cartographica.
* Cartography and Geographic Information Systems.
* Computers and Geosciences.
* Geo Info Systems.
* Geo-Processing (#).
* GIS Europe (#).
* GIS Progressions (#).
* GIS World (#).
* International J. of Geographic Information Systems.
* ITC Journal.
* Mapping Awareness (#).
* Mapping Sciences and Remote Sensing.
* Marine Geodesy.
* Photogrammetric Engineering & Remote Sensing.
* Surveying World (#).

Listed in Table 8.4 are a selection of books on GIS which give a good general coverage at an introductory level.

Table 8.4 Introductory Books on GIS

* Antenuci et al (1991).
* Aronoff (1989).
* Bernhardsen (1992).
* Berry (1993).
* Bonham-Carter (1994).
* Burrough (1986).
* Cassettari (1993).
* CCTA (1993).
* Hart and Tulip (1994).
* Korte (1992).
* Laurini and Thompson (1992)
* Maguire (1989).
* Maguire et al (1991).
* Masser and Blakemore (Eds) (1990).

* Peuquet and Marble (Eds) (1990).
* Star and Estes (1990).
* Tomlin (1990).

Most of the major software suppliers also produce a regular or periodic "newsletter" which is aimed at both promoting their activities and at giving information on recent or forthcoming software improvements. There are also some trade or business directories which, although comparatively expensive, do provide a large amount of valuable information. Three major directories which are published regularly are:

* AGI - Source Book for Geographic Information Systems.
* Cambridge Market Intelligence - GIS Report: A Definitive Guide to Geographic Information Systems.
* Frost and Sullivan - World Geographical Information Systems Software and Services Markets.

8.3.3 Other Guidance and Support

As indicated above, there is now range of support and back-up services available to the GIS sector. These services are mostly supplied by specialist agencies or consultancies, and their existence and location can usually be found through relevant trade directories. Examples of these back-up services, excluding the hardware and software companies themselves, are shown in Table 8.5.

Table 8.5 Types of Back-up Services Which Help to Support GIS

* Management consultants.
* Projects and systems services.
* Quality assurance control services.
* Data conversion services.
* Technical consultancy services.
* Applications development services.
* Survey and mapping services.

A number of learned societies or associations have emerged which are specifically constituted to cater for GIS in individual countries or regions. They are listed alphabetically in Table 8.6.

Table 8.6 The Main Learned Societies and Associations Covering GIS

* AESIGYT (Asociacion Espanola de Sistems de Informacion Geografica y Territorial) - Spain
* AGI (Association for Geographic Information) - UK
* AM/FM (Automated Mapping Facilities Management) - Switzerland
* American Society for Photogrammetry and Remote Sensing - USA

* CCGISE (Canadian Centre for Geographic Information Systems in Education) - Canada
* Centre for Spacial Information Systems - Australia
* CNIG (Conseil National de l'Information Geographique) - France
* EUROGI (European Umbrella Organisation for Geographical Information) - Europe
* GIAC (Geomatics Industry Association of Canada) - Canada
* Kort-Og Matrikelstyrelsen - Denmark
* National Centre of Expertise for Geographic Data-Processing - Netherlands
* NCGIA (National Center for Geographic Information and Analysis) - USA
* NKTF (Norges Karttenkniske Forbund) - Norway
* Polish Association for Spatial Information - Poland
* ProGIS (National Land Survey Department) - Finland
* SPDG (Syndicat Professionnel de la Geomatique) - France
* ULI (Utvecklingsradet for landskapinformation) - Sweden

Major GIS conferences are usually organised annually by learned societies. Some of these conferences are run in conjunction with a trade exhibition. The exhibitions can be a useful way of acquiring general information, of getting an up-to-date view on any software or hardware developments. They are also a useful venue for comparing the relative appearance and performance of competing products. Most vendors will be willing to demonstrate the individual capabilities of their systems. The conferences themselves usually produce useful "Conference Proceedings". The international conferences are shown in Table 8.7.

Table 8.7 International GIS Conferences

* AGI (Association for Geographic Information) - (UK)
* AUTO-CARTO (Automated Cartography) - (USA)
* AM/FM (Automated Mapping and Facilities Management) - (USA)
* Geosciences and Remote Sensing Symposium - (USA)
* GIS/LIS - (Europe and USA)
* GISRUK (Geographical Information Systems Research in the United Kingdom) - (UK)
* EGIS (European Geographic Information Systems) - (Europe)
* ICORG (International Conference on Remote Sensing and GIS) - (India)
* IGARSS (International Geoscience and Remote Sensing Symposium) - (Europe)
* International Symposium on Spatial Data Handling - (USA)
* MARI & Geomercatique - (France)

There are a number of consultants who specialise in GIS. Most of them either specialise in particular areas of study, e.g. Utilities applications, Forestry GIS, GIS for surveying and land planning, etc, or they specialise in particular aspects of GIS such as database structuring and management or systems design. In some countries government information offices can provide details about consultants and organisations such as the FAO or other United Nations agencies have registers of consultants. Alternatively there are a number of directories of consultants.

Many of the trade magazines and the GIS Yearbooks also give details on consultants, e.g. the AGI Geographic Information Source Book for 1994 lists 40 independent GIS consultancy services.

Another way of finding out more about GIS is via computer networking. Once the reader has access to the Internet, then there are a number of networking subscriber lists which can be joined for no charge, and these can be contacted as a method of not only finding out about a range of GIS activities, but also as a means of sending messages in order to solve specific problems. The network can also be used as a basic reference source. So much information is available that it is possible to pursue in some depth almost every aspect of GIS. The quality and quantity of information found on the network may be highly variable from subject to subject, but with new material being added all the time, then it is worth pursuing further. In section 3.3.1 we outlined references to help with networking. There are a number of GIS videos which have been produced and which can now be purchased cheaply. These offer introductions to the potential of GIS from various perspectives. A final way of finding out more about GIS is via bibliographic data searches. Most main public libraries, government department libraries or academic libraries have been implementing various search methods. Some still rely on searching via microfiche, but most are now going over to either straight-forward computer on-line facilities, which show (via a menu system) the contents of the particular library housing the facility, or to specialist CD-ROM disks which contain all the recent publications on a particular subject area.

CHAPTER 9 - SOME CASE STUDIES TO SHOW APPLICATIONS OF GEOGRAPHICAL INFORMATION SYSTEMS TECHNIQUES TO MARINE RESOURCES

Very few studies have yet been published which directly link GIS techniques to marine fisheries applications. This being the case it will be apparent that the studies shown here are mostly applications which have been made to peripheral areas in the field. The studies are therefore mainly concerned with GIS and the coastal environment, mariculture site selection or coastal zone management, or they are perhaps related to other marine fields such as hydrological surveying or the compiling of digital marine atlases. Nevertheless, there are sufficient studies for the reader to acquire a strong impression of the type of potential that GIS presently has to offer. Over the next decade we confidently predict that interest in, and developments of, GIS applications to marine areas will ensure that a rapid adoption rate will take place.

An attempt has been made to structure the content of the case studies in a sequence which looks first at some marine databases and digital atlases. These have been included, even though they are not really GIS's, because many of them either contain GIS generated maps or because there is an intention to eventually develop them into GIS's. We then include some example of coastal zone management and aquacultural GIS's because these provide working examples of marine associated practical GIS applications. Finally we include a miscellany of marine fisheries related GIS studies. Where possible the studies are related to the developing world. We have used the same structure for examining each case study, thus enabling the reader to gain some regularity in the subject content and its presentation. One problem which relates to some of the studies is that, although they all report the use of some level of GIS, there is very little factual information given on the specifics of the system, e.g. the type of software, the hardware configuration, or the amount of emphasis which was put into aspects concerning GIS per se relative to the overall subject matter being investigated.

STUDY 9.1

TITLE:	"Marine Resource Data Base (MRDB): A Database on Vulnerable Marine Resources in Norway."
AUTHORS:	Selvik, J.R., Behren, H.L., Gjetrang, L.M., Langfeldt, J.N., Lystad, E., Marthinsen, I., Moe, K.A., Nedrebo, M. and Skeie, G.M.
PUBLICATION AND DATE:	*Paper Presented at the ICES Statutory Conference.* No.C.M.1993/D:44. Dublin, Ireland.

Introduction/Objectives

It has been recognised that the Norwegian coastline contains some of the most important marine areas in the world, both regarding exploitable and non-exploitable resources. Many of these resources are already being heavily exploited, and there is a need to ensure that precautionary measures are in hand in case of accidents or emergencies. For this reason a consortium of nine major companies operating on the Norwegian shelf waters commissioned a group of marine scientists in 1987 to develop a marine resources database (MRDB). They have been assisted in this project by other government agencies. The database is now available and it provides information on the whole of the coastal area for mainland Norway and for Spitzbergen, i.e. 57 000km of coastline as well as 950 000 km^2 of shelf and oceanic waters.

Methods/Equipment

The database used for holding the information is "4th Dimension", an Apple Mackintosh" relational database. Data for the databases was obtained from more than 300 official publications or scientific articles, and information is included on more than 22 000 sites. There are 15 major files, which are related as appropriate. A special "sub-GIS" programme, called GEDAP, has been developed which interactively allows data to be displayed on previously vectorised digital maps at any resolution. An example is shown in Figure 9.1.

The information in the MRDB is categorised through a three tiered system. The main database areas covered which are of interest to fisheries include:

a) Marine mammal sites,
b) Aquaculture installations,
c) Commercial fisheries,
d) Fish resources,
e) Nature conservation areas.

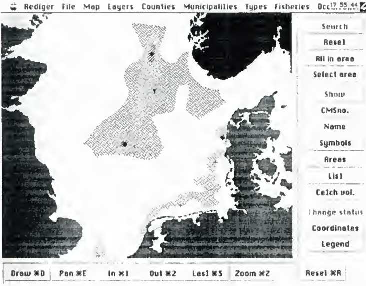


Figure 9.1 A Typical Screen Display for the Norwegian MRDB, Showing the Distribution of Mackerel Eggs in the North Sea in June, 1990

Within each of these major categories there is information where appropriate, relating to fields such as - administrative unit, location, conservation criteria, species information, etc. From each of these there are subtypes. Thus species information may include - eggs, larvae, spawning areas, 0-group, nursing area, post larvae, fingerlings, etc. The authors outline the difficulties which they experienced in trying to unite data which had its origins in many diverse sources. Typical difficulties included error correction, adding geo-references, incomplete data sets, differing data interpretations, etc.

Results/Discussion/Conclusions

The data is now available for use. One of the main uses has been in putting together Environment Impact Statements, though it is also being used in modelling likely environmental impact scenarios, e.g. to show what would happen to a species spawning ground if a pollution incident occurred given a certain date, wind speed and direction, quantity of pollutant, etc. The system appears to be functioning particularly well, and a Microsoft Windows based version for PC's has already been released. As the authors note, at the present time this system is really

only a database with a mapping graphics add-on which has an extremely limited recognisable GIS functionality. However, it is important to stress that the system as outlined is one legitimate way of entering the GIS field, and it would take very little extra work to add functionality to this basic system. As the quality of the databases improve, this is undoubtedly what will happen.

STUDY 9.2

TITLE: "The Skagex Atlas - User's Guide."

AUTHOR: Ostrowski, M.

PUBLICATION AND DATE: Funded by International Council for the Exploration of the Seas (ICES) and the Nordic Council of Ministers. Bergen (1994).

Introduction/Objectives

The Skagex Atlas is a computerised data atlas consisting of a set of databases plus their managing software. It contains all the data collected by marine scientists from seven Baltic area countries, whilst carrying out joint fieldwork in the Skagerrak and Kattegat Seas during 1990 and 1991. Data was collected on physical, hydrochemical and biological parameters and then centrally submitted to the ICES Data Centre, who worked them up into a coherent database. In order to make this database more accessible to all the SKAGEX scientists, in 1991 the author proposed that he use his in-house software, a marine data management system, to create the Skagex Atlas. In April, 1992 the first version of the digital atlas was ready. It has since been refined and updated.

Methods/Equipment

Contrary to its name, the Skagex Atlas is not a ready set of digitised charts. Instead it is a collection of databases carrying the results of all the in situ sampling carried out by the Skagex marine scientists. The database is divided into records, each of which corresponds to an oceanographic station. The records (stations) are indexed by platform (ship) identifiers, and location/time coordinates of each sampling event. For each station the datacycles with results are structured into a simple table where columns pertain to parameters and rows to depth levels. The Atlas software provides integrated tools for browsing and downloading data subsets from the databases. All subsets can be visualised in terms of x-y plots, sections and maps showing horizontal distributions of the sampled parameter (Figure 9.2). The atlas's own software is linked with a commercial 3-D graphics package called SURFER to produce this output.

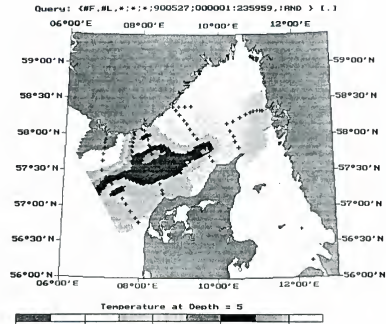


Figure 9.2 Example of Skagex Atlas Output Showing a Black and White Copy of a Colour Raster Image of Temperature Distributions at 5 Metres Depth on 27th May, 1990

The data forming the databases was collected from 17 stationary oceanographic vessels using probes and water bottle samplers. Samples on the main parameters of temperature, salinity, phosphate, nitrate, nitrite and silicate were taken from up to 15 different depths, ranging from 1 to 600 metres. Most of the data was collected along seven obligatory tracts during May and June of 1990 at coordinated times (Figure 9.3). Whilst not collecting data along these tracts, vessels collected discretionary data which is also in the main ICES database and is accessible to the Atlas. Some of the obligatory transects were re-surveyed at later dates in September, 1990 and/or January, 1991. As of 1994, data sets covering primary productivity of phyto- and zooplankton were not accessible, though they will be available at a later data.

The Atlas software is designed to run on IBM PC computers having a hard disk. It requires 15MB of free disk space for the databases. The minimum hardware configuration should include an 80286 processor plus a maths coprocessor and 600Kb of free RAM memory. The Atlas is

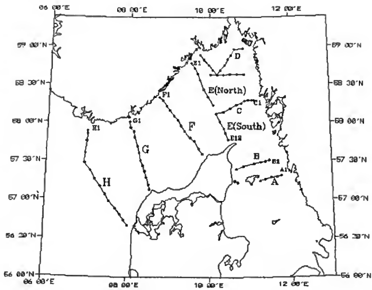


Figure 9.3 The Main Transects from which Data was Gathered for the Skagex Atlas

user friendly being menu driven usually with the use of a mouse. Colour display is optional. The hard disk should also contain Microsoft DOS version 5.0 or higher plus the SURFER 3-D graphics package (version 4.11 or higher). The Atlas software can now also be run from Microsoft Windows.

Results/Discussion/Conclusions

This Atlas is clearly an example of a fairly basic way in which some GIS functionality can be obtained. Thus the Atlas software allows the databases to be transformed such that visual mapping displays are obtained for a range of parameters, and the user has a degree of control over the output required. The User's Guide sets out in detail all the various commands (the user interface), and how to process the data into a form for presentation of maps, sections or graphs. It also outlines the various printing or plotting capabilities.

STUDY 9.3

TITLE: "Marine Resource Atlases: The Implications for Policymakers and Planners."

AUTHOR: Ramster, J.

PUBLICATION AND DATE: *Underwater Technology*. 1994. Vol.19, No.4. pp12-19.

Introduction/Objectives

In this case study we shall review the United Kingdom Digital Atlas Project (UKDMAP), although the journal paper also looks at other similar atlas and marine database developments. UKDMAP has also been described in Ramster (1991) and Robinson (1991), though both of these papers describe version 1. The UKDMAP was developed by the British Oceanographic Data Centre (BODC), in collaboration with other data providing agencies, as a reference work on the seas around the British Isles. Version 1 was released early in 1991, version 2 in mid 1992 and a Windows version has recently been released. The Atlas contains 462 different maps (charts) under the variety of different datasets shown in Table 9.1. For every one of the charts there is an "Information" box, which provides varying details on the chart, its data sources and where further information can be obtained.

Table 9.1 The Main Mapping Themes Contained in the United Kingdom Digital Marine Atlas

* General reference	18 charts
* Marine geology and geomorphology	11 charts
* Marine and coastal parks, reserves and protected areas	15 charts
* Marine and coastal conservation in Great Britain	8 charts
* Sea birds	25 charts
* Sea mammals	11 charts
* Marine biology	29 charts
* Currents, tides and surges	19 charts
* Winds, waves and weather	21 charts
* Seawater temperature, salinity and nutrients	162 charts
* Chemical distributions	33 charts
* Exploitation of the marine environment	12 charts
* Fishing areas and fish spawning areas	24 charts
* Fishery statistics	50 charts
* British Oceanographic Data Centre - data catalogues	24 charts

Methods/Equipment

The Atlas runs on an IBM PC with 640Kb of RAM, an EGA or VGA display and a hard disk with at least 10MB free for running and installation. It uses the Microsoft DOS operating system (Version 3.0 or later), preferably a mouse and it can be networked for multi-user operation on a LAN. Output to most laser or dot matrix printers is possible.

The Atlas is very "user friendly". It is controlled by a system of pull down hierarchical menus, backed up by a context sensitive help system. Information within the Atlas is presented as a series of colour charts which the user may browse, zooming into areas of specific interest, and overlaying with information from another chart for comparison purposes. The "Information" boxes can be superimposed on charts for reading or printing. Figure 9.4 gives examples of UKDMAP output. There are options to change or customise any of the colour shadings on the charts as required, and to place a reference grid over any chart. There is also an interactive cursor which allows latitude and longitude coordinates to be read, or which allows distances to be calculated along user plotted lines at any scale. The atlas has a "save screen display for slides" allowing charts to be viewed outside the system using the "Slideshow" programme provided.

Results/Discussion/Conclusions

Digital atlases of this kind offer a number of advantages over traditional atlases. Thus the user has the ability of manipulating the presentation of charts to his advantage according to specific needs. Scale changes can be instantly carried out. Bringing out a new addition is simple in the sense that adding new information to any disks for retailing in an updated version, is a far cheaper proposition than reprinting and supplying a new hardcopy edition of such an Atlas. This also means that a far greater range of material can be provided for comparatively little extra effort. The success of this Atlas format has been such that several new and similar marine atlases are planned by the British Ministry of Agriculture, Fisheries and Food.

Although the Atlas is not a true GIS, it goes some way to providing some limited functionality of a GIS. Thus the overlay facility, querying and distance measurements are all basic GIS prerequisites, and they provide excellent illustrative concepts of what the scope of a GIS might begin with. Also, this type of product could well take on board more GIS analytical capabilities in future releases.

STUDY 9.4

TITLE: "Protecting the Environment: GIS and the Wadden Sea."

AUTHOR: Liebig, W.

PUBLICATION AND DATE: *GIS Europe*. Vol.3, No.2. pp34-36. 1994.

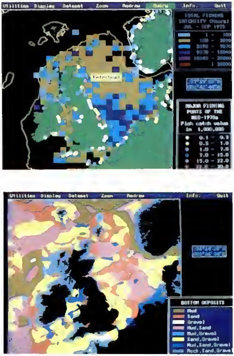


Figure 9.4 Examples of output from the United Kingdom Digital Marine Atlas

Introduction/Objectives

The Wadden Sea consists of about 8000 km² of sheltered waters which stretch along the coastline of mainland Europe between northern Holland and western Denmark. The Sea forms a somewhat unique natural habitat consisting of very shallow waters, having strong tidal currents, and being surrounded by flat islands of sand and grasses, plus dunes, beaches, salt marshes and tidal flats. This environment is presently under threat from dyke building, agriculture, fishing, tourism and recreation, plus pollution from the North Sea and nearby rivers.

In order to give a measure of protection to this coastal environment, the Danish, German and Dutch governments have declared that much of the area should be designated as protected

national parks. Allied to this a number of research stations have been set up, and projects have been instigated, which have an interest in studying the area's hydrology, geomorphology and biology, plus the various impacts on this fragile environment from human activities. This particular study was carried out from the Coastal Research Station at Norderney in northern Germany.

Methods/Equipment

Since a large number of spatially related databases had been set up, and since there were sufficient and varying existing maps, then GIS was considered to be an appropriate tool for the analysis and representation of the hydrological, geomorphological and biological data and their interactions. This included the development of mathematical models to show simulated current and wave movements which would help in formulating sediment transportation paths. The Research Station was fortunate in having long term data covering, for some data, the period back to 1650. The actual GIS work commenced in 1990, and GIS is now being used for a variety of projects.

All the data gathered are held on a mainframe VAX computer which itself formed part of a Local Area Network (LAN), of which the GIS was just one constituent. The GIS used was ARC/INFO, incorporating their TIN and GRID modules, and running on a DIGITAL-5000/125 workstation. A DIN A/0 digitiser, plotter and laser printer were also used.

One of the main purposes of work being carried out at Norderney is to investigate the morphological development of the Wadden Sea. Once digitised maps had been produced, Triangular Networks (TIN's) and lattices (3-D surfaces) could be calculated, the latter forming the basis of a regular grid. This grid was necessary as a basis on which to perform inter-cell comparisons, i.e. to show, and to calculate, morphological changes from one date to another. The grid was also used in the development of the wave and current flow models.

Results/Discussion/Conclusions

For some of the GIS output it was simply a case of digitising various maps in order to create separate layers, and then to use the GIS to combine these layers to produce new maps. Figure 9.5 is one such example. It shows, at a fairly small scale, the Wadden Sea area for the German state of Niedersachsen. The green areas represent offshore islands, and the orange represents the tidal flats. For one detailed area of the map the sediment distribution is shown, though more detail on sediments and wave heights in this area is given in Figure 9.6. Information on wave heights has been calculated using a specially developed mathematical wave propagation model which allows height to be calculated at all of the lattice points, i.e. given various wind and morphological conditions. The GIS was used not only to prepare the maps, but also to calculate various combinations of wave parameters such as height, length, and period at each lattice point. These types of map typify the GIS output which is requisite in coastal zone management studies.

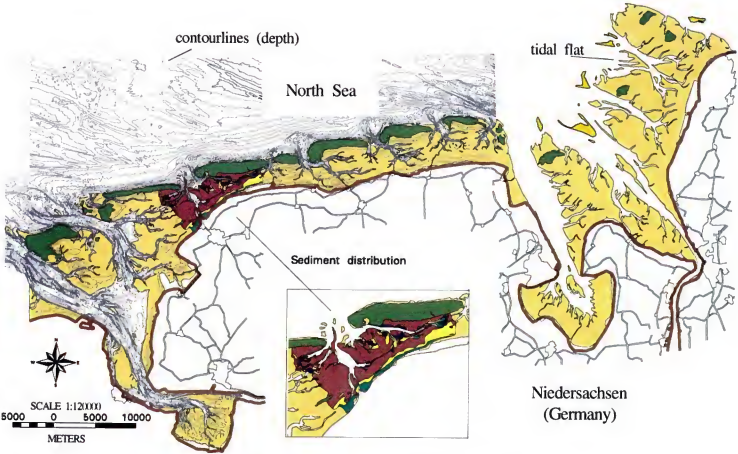


Figure 9.5 Coastal Zone Map of the Wadden Sea Area of Northern Germany

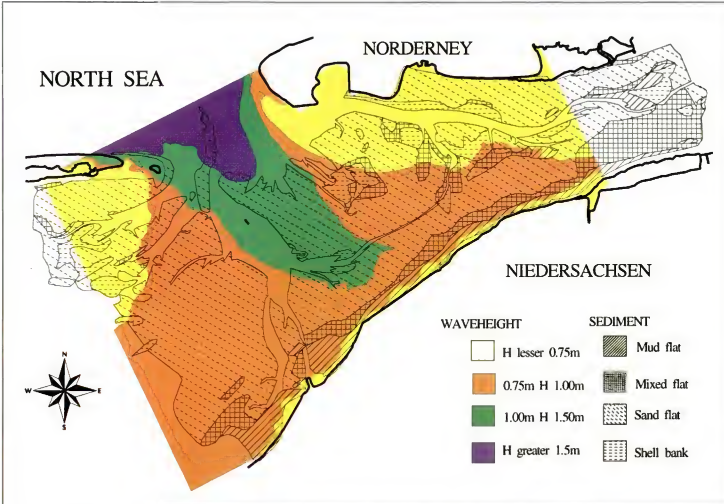


Figure 9.6 Wave Height and Sediment Distribution Over Tidal Flats Near Norderney.

From these two Figures it is clear that GIS is being used here in a very specific and fairly sophisticated way, and the author is able to show a number of other uses to which the GIS has already been put. Thus analyses have been done which relate wave height to channel depth or wave height to sediment type, and which explain changes in morphological characteristics over time. This work should go some way to resolving the dynamics of the assorted natural processes which are occurring in the Wadden Sea area, thus ensuring a better long term future. This is important since, although the author does not mention it, parts of the Wadden Sea form the major nursery area for the southern North Sea plaice stock, one of the major commercial fisheries in Europe.

STUDY 9.5

TITLE: "Use of High Resolution Satellite Data for Coastal Fisheries."

AUTHOR: FAO

PUBLICATION AND DATE: *FAO Remote Sensing Series No.58.* 1991

Introduction/Objectives

This study is one in a series of publications which have been published by the FAO, and which are aimed at presenting various project managers with the possibilities that are offered by the use of remote sensing as an aid to resource management. This case study does not actually use GIS directly, but it is an excellent example of how data can be gained which is both in a correct format and of a high quality i.e. such that it can be directly input into a GIS.

The coastal zone in many developing countries is under tremendous pressure, especially certain fragile environments such as mangroves or coral reefs which are effected by a variety of marine and land based economic activities, and which are easily destroyed. In many areas of the world these coastal areas have been insufficiently mapped for management or monitoring purposes. The main objective of this study was to show how remote sensing capabilities (specifically the use of SPOT imagery) are now such that they can allow for extremely detailed maps to be drawn up, in this case showing all the features associated with an intertidal zone in Quezon Province of central Luzon in the Philippines. This region is naturally covered by mangroves plus areas of coconut trees, and some mariculture facilities are already in operation. The population density is high and most people are employed in small scale coastal fisheries.

Methods/Equipment

All the necessary image processing was carried out at the FAO Remote Sensing Centre in Rome. A SPOT image dated 5th February, 1988 was used as the basis for the exercise. This image, in

multispectral mode at 20 m resolution, was pre-processed by SPOT to level 2A in the UTM cartographic projection. Some land use maps were also used in the production of the final map output. Ground truthing was necessary as a means of verifying the reflectance values, and field surveys were undertaken for this covering aquatic and terrestrial environments. Obviously, before final output could be obtained various image processing procedures were necessary, and these are described in detail in the original text.

Results/Discussion/Conclusions

Figure 9.7 shows a final map which was published. The scale is at 1:50 000 and the imaging processing methods used allows the map to differentiate between a large number of tidal and shallow water features. The terrestrial features shown would have been added using information from local topographic map sources. Of prime interest for fisheries purposes, the map gives indications of:

a) The coastline. This is of a high resolution and the satellite data could provide an outline which was geometrically correct.
b) The intertidal area. It was possible to distinguish a number of separate land use categories and existing aquaculture ponds. c) Shallow water areas. In clear waters up to a depth of 10 metres it was possible to identify both bottom types and to draw 3m and 10m bathymetric lines.

The maps could be used to update nautical charts, to locate seaweed resources, to select potential aquaculture pond or cage sites, to monitor the environment or to assess existing land uses.

This project was also able to calculate the relative costs of obtaining this type of information, and it was found to be cost effective vis a vis the main alternatives. Because of the number of complex processes involved before the final product could be produced, this type of mapping data can take some time to achieve, e.g. perhaps a one year period to obtain details on up to 20 000 km^2 of coastal zone. With new satellite programmes coming on stream, and with the release of much previously unavailable Russian data, then future costs of obtaining data in this way are likely to fall. Although the work for this study was done by the FAO in Rome, the publication states "... technology transfer to a developing country can be accomplished with minimal international assistance at a reasonable cost."

STUDY 9.6

TITLE: "Coastal Zone Mapping."

AUTHORS: Harper, B. and Curtis, M.

PUBLICATION AND DATE: Mapping Awareness & GIS in Europe. (1993) Vol.7, No.1. pp17-19.

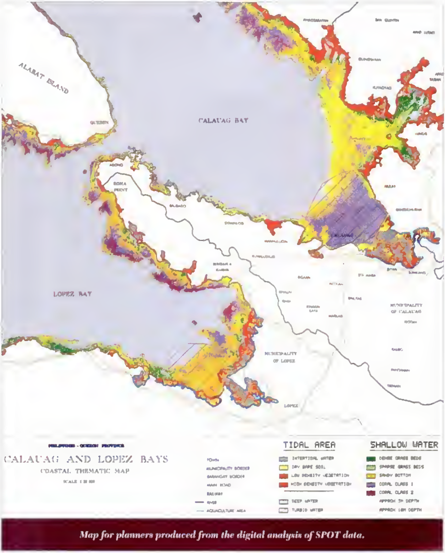


Figure 9.7 **Map Showing Coastal Intertidal and Shallow Water Zones for Part of the Lamon Bay Area of Luzon Island in the Philippines**

Introduction/Objectives

There is widespread recognition that various types of coastline are under particular types of pressure. With this basic fact in mind, the UK Hydrographic Office (HO) and the Ordnance Survey (OS) have undertaken a joint pilot project to produce both a paper and digital version of coastal zone maps. These two organisations jointly hold the national databases for sea and land based information. At the present time only a pilot set of maps have been produced which cover the marine area called the Solent, i.e. which separates the Isle of Wight from mainland England. The interpretation of "coastal zone" is rather flexible, though it is intended that the seaward side should range out as far as the 12 mile fishery limit. This particular project will not be taken beyond the pilot stage until user needs have been identified.

Methods/Equipment

Initial difficulties were encountered in producing the prototype coastal zone map because the necessary data kept by the HO and the OS were in different forms and/or formats. Because of this it was not simply a case of joining in an agreed way two sets of digital data. The digital data for each mapped theme, e.g. bathymetric lines, roads or saltmarsh, was therefore derived by selective scanning, either from the high quality positive film held by the OS or by scanning from HO charts. OS topographic maps at scales from 1:10 000 to 1:50 000 were used, plus HO charts at various scales. This produced high resolution raster image data, which was either converted to vector format using the PAFEC Raven system, or which could be used as obtained. The resulting vectors needed to be "cleaned up" using various automated processes, and to be features coded. The vectorised data for all 32 layers used was then transferred to an Apple Macintosh Desk Top Mapping Production system, with a Macintosh Quadra 700 computer being used. Here the various layers could be combined and any necessary refinements were made using Freehand 3.1 software. Printing was via the screen image to a Canon CLC10 copier.

It was necessary to give a great deal of consideration as to which features were to be maintained from both the HO and OS datasets. Some features were left in their original format because of map user familiarisation but, since this was to be a purposefully made map product, other features were enhanced in order to better convey specific information. Completely new features were added, some changes were made to traditional colours, and colour fills were given to the highlight water depths. Figure 9.8 gives a useful indication of the hydrographic features which were selected for inclusion on the map.

Results/Discussion/Conclusions

Having acquired the digital version, then the user is able to enter it into any GIS to be manipulated as desired. Either the vector or raster data could be used. Once in the GIS then the possibilities for its use are huge. Figure 9.9 illustrates how a user has overlaid his own vegetative data on the basic coastal zone map. The main problem with regard to further digital coastal zone mapping lies in whether there is sufficient demand from customers who can afford the relatively high costs involved. Undoubtedly, costs would be significantly reduced if all the initial data required were to be held in a digitally standardised form.

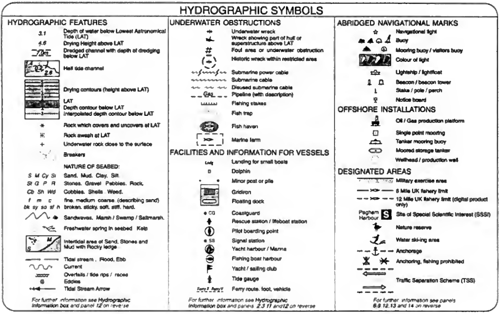


Figure 9.8 **The Hydrographic Symbols Displayed on the Pilot UK Digital Coastal Zone Map**

STUDY 9.7

TITLE: "The Use of Geographical Information Systems for Site Selection for Coastal Aquaculture."

AUTHORS: Ross, L.G., Mendoza, E.A. and Beveridge, M.C.M.

PUBLICATION AND DATE: *Aquaculture* (1993). Vol.112, No.2-3, pp165-178.

Figure 9.9 A Displayed Portion of the Pilot Coastal Zone Map Overlaid with User Defined Vegetation Occurrences

Introduction/Objectives

Although growth in aquaculture has been quite spectacular recently, there have also been a large number of business failures. One of the reasons for this has been a lack of knowledge on the aquatic environment and the use of unreliable means for resource assessment. To plan successfully it requires both reliable data and a way of processing the data. Until recently the means of processing the data has often been limited, and the acquisition of reliable data is still a problem throughout much of the world. The advent of GIS as a tool for planning has now become accepted, and some applications in aquaculture development have already been made. Most of these have been carried out at the regional scale. This study seeks to show the use of

GIS for detailed site selection at the micro scale. The paper describes the implementation of a PC-based GIS to assess the potential for salmonid cage culture development in Camas Bruaich Ruaidhe, a small bay in Argyll, Scotland.

Methods/Equipment

The GIS software used was "OSU-MAP for the PC", a raster based package developed at the Ohio State University. Though the software is very unsophisticated, it is well suited to small research projects. A 80386 processor was used plus an HP7475A plotter and an HP Laserjet IID printer. Although the study was first reported by Mendoza (1990), and was outlined in Meaden and Kapetsky (1991), the work has been substantially advanced since then.

For input into the GIS, data had to be gathered on the following production criteria:

(a) Topography. A detailed topographic map had to be drawn up, using plane tabling and levelling techniques, at a scale of 1:2000.
(b) Bathymetry. A bathymetric contour map was prepared by using a Lowrance echosounder to take readings in several transects across the bay. This was plotted out at a scale of 1:2000, with a 2 metre contour interval.
(c) Currents. Current velocities and directions were measured at different tidal states using hydrographic drogues.
(d) Exposure. This was classified by estimating wave height at different locations. Wave height would depend on wind direction, velocity, duration and fetch. Wind data was obtained from a nearby weather station and fetches were calculated from a local topographic map. Heights were predicted using graphs available in published sources.
(e) Water quality. Vertical profiles of dissolved oxygen, salinity and temperature were made from a number of different locations in the bay.

Data on the above parameters were prepared for input to the GIS at two different scales so that a comparison of the results could be made. Scales were chosen so that each data block represented either a 25 x 25 metre cell (total 576 cells) or a 10 x 10 metre cell (total 3600 cells). Data values were calculated by laying a transparent grid base over the appropriate mapped representation of each production criteria, and then reading off the values. Other information was added to the database by taking the information straight from topographic maps, e.g. the outline of the bay and the location of main roads.

Results/Discussion/Conclusions

Generally, the bay should make a good site for coastal aquaculture. It is easily accessible, electricity is close by as are labour supplies, services and other supplies. There is also no source of pollution nearby, it is little used as a recreational resource and there are no shipping lanes to be wary of.

The authors produce for discussion maps on each of the production criteria. The main findings on each were:

(a) Bathymetry. The mean depth of the bay was 6.8m, and about half of the bay had suitable depth profiles.
(b) Currents. There was an anti-clockwise current pattern with highest velocities of about 130 cm per second occurring along the eastern side of the bay. 80% of current speeds were within acceptable limits.
(c) Dissolved oxygen. Levels varied slightly between high and low tide, but they were in the range of 8.2 to 11.0 ppm. Vertical profiles were uniform. DO was not considered to be a limiting factor.
(d) Water temperature. This varied from 12.8 to 13.0 C. Although there would clearly be seasonal variations, these were not within a range where limitations would be placed upon production.
(e) Salinity. Although there was no vertical stratification of this parameter, there were clear differences between ebb and flood tides. These were sufficient to make a marked difference in the aquatic environment and therefore to the salmonid production potential.
(f) Wind speeds. This parameter was also highly variable, mostly according to length of fetch. Wave heights were calculated and mapped such that a worst case situation was allowed for.

Having established the existing parameters, the authors then used a processing sequence for site selection. This essentially meant that, having decided upon suitable parameter ranges for aquacultural production, then scores had to be allocated according to the degree of suitability (Table 9.2). Once the scoring sequence had been undertaken, then cells showing the highest scores should prove most suitable (Figure 9.10).

The map which had a resolution of 25 x 25m cells was found to be of too coarse a resolution, though the authors suggest that this scale may be alright if a very large raft of cages were having to be sited. Though the GIS approach was considered to be very satisfactory, there would continue to be a problem in obtaining some of the data. So, for instance, it is doubtful if suitably detailed bathymetric data would ever be available, and data on current velocity, water quality and wave height would also need to be calculated from field investigations in what could be a costly and time consuming process. As a general comment, care would also need to always be taken when constructing maps based upon interpolated data covering large areas in dynamic environments. From a time/cost perspective, estimations on the use of GIS vis a vis manual methods proved GIS to be very efficient i.e. the time taken to process all the data manually was about 40 hours, whereas only 19 hours were needed to process the data for GIS use.

It is important to recognise sources of error which may result from the GIS approach. These may be due to inaccurate source data, poor parameter choice and inappropriate scoring methods. The authors were able to compare the GIS results with those done by a manual survey carried out by nine skilled volunteers. It is interesting to note that the manual survey found that about 40% more of the bay was suited to aquaculture than the GIS survey found, but there was a huge

Table 9.2 The Processing Sequence and Scores Added for Each Production Parameter in Salmonid Aquaculture Site Selection in Scotland

Source Layer & Resultant Layer	Process step	Scoring criteria	Scores
BATHY	Select depths over 6m	Less than 6m	0
		6m and above	1
BATHGRAD			
WAVEDIST	Cross with BATHGRAD and score	Wave height <60cm	1
		Wave height >60cm	2
SAFEWAVE			
CURR-INT	Cross with SAFEWAVE and score	Waves <60 cm	
		Currents <50 cm.sec^{-1}	1
		Currents >50 cm.sec^{-1}	2
		Waves >60 cm	
		Currents <50 cm.sec^{-1}	3
		Currents >50 cm.sec-1	4
BAWVCURR			
SALEXT	Cross with BAWVCURR and score	Salinity variation	
		8ppt	1
		>8ppt	0
*D.O.	Cross with BAWVCURR and score	D.O. <6mg.l	0
		D.O. >6mg.l	1
*TEMP		Temperature <5 °C	0
		5 - 10	1
		10 - 15	2
		>15	1
FINAL			
FINAL	Cover SITE with FINAL to show end result		
SUITABLE			

* These were not considered in this GIS

variation between individual assessments. This could show that manual assessments are prone to bias, and this large variability could have severe economic implications for an aquacultural development.

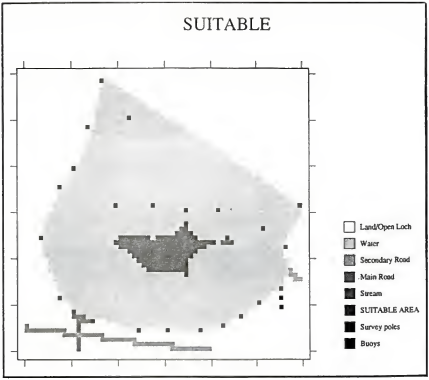


Figure 9.10 Cells Which Should Prove to be Most Suited for Salmonid Aquaculture in Camas Bruiach Ruiadhe Bay, Scotland

STUDY 9.8

TITLE: "A Geographical Information System to Plan for Aquaculture: A FAO-UNEP/GRID Study in Costa Rica."

AUTHORS: Kapetsky, J.M., McGregor, L. and Nanne E., H.

PUBLICATION AND DATE: *FAO Fisheries Technical Paper No.287.* (1987)

Introduction/Objectives

The authors initially outline the reasons why, despite the tremendous needs, the planning process itself for developments such as aquacultural facilities has been very slow to materialise. With the emergence of GIS capabilities, there is now the a means whereby the manipulation, analyses and evaluation of large amounts of data is possible, such that reliable decisions concerning locations and development planning can be made. The particular objectives of this study were to establish the feasibility of using remote sensing and GIS as tools in assessing the opportunities for coastal aquaculture, and to see where the most promising opportunities were for this aquaculture (including how much land and water was available).

The area of study chosen for these tasks was the Gulf of Nicoya, on the Pacific coast of Costa Rica. This area was selected since its environment offered the essentials for aquaculture, since there was strong competition for local land resources, and because there was already some culturing going on here which would offer the opportunity to check the results obtained against any existing information. The present culturing consisted of some semi-intensive shrimp ponds although the development of mussel culturing is under investigation. The authors give a detailed geographic study of the relevant physical and social conditions which exist in the Gulf area. The main factors to note are:

(a) The Gulf shoreline is mainly fringed with mangroves interspersed by hilly areas.
(b) The surrounding land is mostly pastoral.
(c) There few large centres of population.
(d) Year round temperatures are high and there is a rainy season from May to November.
(e) The waters at the head of the Gulf are mostly less than 20m deep, though they rapidly deepen towards the entrance.
(f) There are extensive inter-tidal flats at the northern end of the Gulf.
(g) Salinity is a function of the tidal state and the season and also of current flows which cause the eastern side to be less saline.
(h) Water temperatures are in excess of 25 C but tend to be stratified in the dry season.
(i) Dissolves oxygen levels are frequently low in the upper Gulf, especially during the dry season, i.e. given the low water change and high primary productivity.
(j) High levels of ammonia result from water run-off from the pastoral lands.

The bulk of this study is focused on the inner Gulf area where it was obvious from an initial analysis that more aquaculture potential lies (Figure 9.11). In this area the greatest potential would seem to be in (i) the raft or longline culturing of molluscs in intertidal and subtidal waters, (ii) the extensive culturing of shrimp in former solar salt ponds and (iii) semi-intensive shrimp production outside of mangrove areas.

Methods/Equipment

The software used in this study was ELAS, which is essentially an image processing system with the capability of integrating other geo-referenced data. The hardware used included a Perkins-

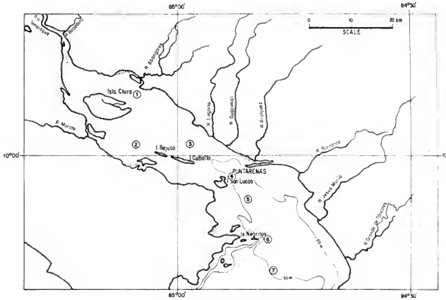


Figure 9.11 General Features of the Gulf of Nicoya, Costa Rica

Elmer 3241 computer and a Calcomp 6000 for digitising. Analyses and processing were carried out at the Global Resources Information Database (GRID) facility in Geneva, Switzerland.

The criteria used to assess aquaculture potential are shown in Table 9.3. For each of the criteria it was necessary to establish the range of conditions in which it would prove possible to function in and to identify optimum conditions. A variety of methods was used to obtain the necessary data. Thus salinity level data was obtained from previous survey data, bathymetric data from published nautical charts, and shelter and security data was based on wind speed meteorological data adjusted so as to provide an indication of the likely wave height according to the fetch and water depth. Information on land use was obtained from a Landsat Thematic Mapper image dated 15 April, 1985 and verified by ground truthing during July, 1986. The existence of the solar salt ponds was also obtained from this image. Water quality data was inferred from land use, i.e. such that mangroves gave best quality water, then forest, then rangeland, then pasture and finally cropland would result in the worst quality water. Information on the infrastructure was obtained from the national topographical mapping series at 1:500 000 scale. Soil data was obtained from national soil maps at 1:200 000 scale and their suitability for pond lining was

assessed and given a "relative suitability" score. The authors explain in some detail both the purposes for including the "proximity" and the "shrimp post-larval density" data, and the ways in which this data was calculated from existing information.

Table 9.3 Criteria Used to Identify Opportunities for Aquaculture in the Gulf of Nicoya, Costa Rica

	Organisms and Culture Methods				
	Molluscs		Fishes	Shrimps	
Main Criteria and Sub-Criteria	Intertidal	Subtidal	Suspended	Extensive	Semi-intensive
Salinity	X	X	X	X	X
Infrastructure	X	X	X	X	X
- Villages					
- Roads					
- Ferries					
- Processor					
- Electrical service					
Land Uses					
- Water Quality	X	X	X	X	X
- Site acquisition costs					X
- Site development costs					X
- Mangroves	X	X			X
Bathymetry	X	X	X		
Shelter and Security					
Shrimp post-larvel density				X	X
Proximities					
- Perennial rivers					X
- Saltwater					X
Soils					X

Results/Discussion/Conclusions

The authors initially provide a very detailed analysis of the potential for aquaculture under each of the three main types envisaged (as listed above). Space here prohibits a detailed review, but a summary of their findings would be:

(a) Intertidal, subtidal and suspended culturing. About 14% of the inner Gulf would be suitable for this activity. The best areas are in the vicinity of Chira Island. Altogether, there are about 9 000ha of subtidal waters which are both sheltered and suitably protected. In the main these areas have the requisite lower salinities for the rearing of euryhaline organisms. One problem with these optimum areas is their relative isolation from the main urban area of Puntarenas, although it is likely that counter benefits will be obtained from the higher quality waters. About 950ha of intertidal water was found which would prove suitable for aquaculture. Figure 9.12 shows the optimum locations for the three types of culturing; purple indicates areas of mangroves.

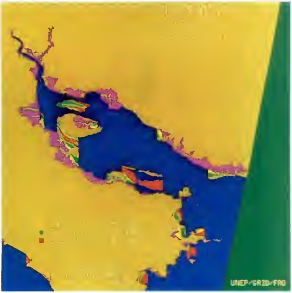


Figure 9.12 Location and Surface Areas for the Development of Intertidal, Subtidal and Suspended Cultures in the Gulf of Nicoya, Costa Rica

(b) Extensive aquaculture in solar salt pans. 80 salt pans having a total of area of 656 ha were detected by satellite remote sensing. Those which offer the best aquacultural potential will be where shrimp post larvae from the wild are most abundant, where pond salinities can be manipulated and those which are supported by good communications to the markets at

Puntarenas. Some 23% of the available salt pond area was found to best meet the selection criteria, and these were mostly on the northern Gulf shoreline near to the mouths of rivers from where fresh water could be obtained. The infrastructure was also relatively good here.

(c) Semi-intensive shrimp farming outside mangrove areas. Some 2232 ha of land meet the necessary criteria for this activity. This falls into four areas on the northern Gulf shoreline and one in the south. Again it is the availability of the infrastructure which gives priority to these areas. The results obtained seem to justify the proposed methodology, though the authors rightly suggest that they are only indicative and that more detailed field investigations would be necessary before actual aquacultural sites were selected. One of the major problems to a study of this kind is the variability of the source data, i.e. both in its accuracy and scale. Therefore the use of GIS will only provide more reliable information when input data are more reliable. The authors suggest a number of ways in which the input data could have been added to, or improved upon, but to achieve this would require huge additional cost and effort inputs. The study concludes with an interesting analysis of the utility of using GIS and remote sensing in an exercise such as this. The conclusion is also of interest from the viewpoint that, since this study was produced in 1987, many of the conclusions concerning matters of cost and efficiency have been superceded through the pace of change in GIS developments and applications, i.e. such that GIS now has a far greater utility than it did a decade ago.

STUDY 9.9

TITLE: "Using a Geographic Information System to Evaluate the Effects of Shellfish Closures on Shellfish Leases, Aquaculture and Habitat Availability."

AUTHOR: Legault, J.A.

PUBLICATION AND DATE: *Canadian Technical Report of Fisheries and Aquatic Sciences No.1882E.* (1992).

Introduction/Objectives

Throughout much of the Atlantic seaboard area of Canada municipal sewage is disposed of directly to the sea without having been treated. The waters therefore become contaminated with bacteria, viruses and toxic chemicals. This situation is exacerbated by industrial discharges and agricultural run-off. Based on guidelines covering specific contamination levels, issued jointly by the Department of Fisheries and Oceans (DFO) and the Department of the Environment (DOE), the authorities are regularly forced to close the shellfish beds in specified areas for varying lengths of time. These closures effect both aquacultural and "wild" shellfish harvesting, and this action inevitably has a strong effect on the local economy. In order to monitor this situation and to try to produce a remedy, the DFO's Marine Atlantic Standing Sub-Committee

on Habitat (MASSH) funded a pilot study to quantify the shellfish habitats affected and the shellfish markets lost or jeopardised as a result of the closures. The pilot study was based upon the eastern coast of Prince Edward island in the Canadian Maritime Provinces.

Methods/Equipment

The study utilised the Computer Aided Resource Information System (CARIS), which uses an INGRES relational database, running on a MicroVaxII with a VMS operating system. The author explains how the necessary digital mapping outlines and data on pollution sources and shellfish closures was obtained from various sources. As an end product, the GIS was expected to produce output showing the coastline features, shellfish closure zones,shellfish approved zones, shellfish leases, land-based pollution sources, plus corresponding tables of data.

Results/Discussion/Conclusions

It was found that the system was able to meet the above criteria except that the size of the hard disk space was insufficient for all tasks, and that the system needed to be more user friendly. Both of these problems could be easily rectified. The author shows and discusses examples of the variety of output which could be achieved by use of the CARIS system. These ranged from simple outline maps of the region, through maps showing the shellfish harvesting zones, maps showing the point sources of pollution, to maps such as Figure 9.13 which shows a specific portion of the area in some detail. Notice that lines can be generated which join given co-ordinates so as to delimit enclosed polygons (in this case individual or grouped rivers). This functionality is useful for indicating any shellfish closure areas. Area calculations can be made of the size of such closed polygons, and shading can be added so as to enhance the visualization of the map.

Since the input data to CARIS contained a large amount of varied database information, then a varied range of tabular output could be generated. Figure 9.14 illustrates tabular output, in this case giving an indication of shellfish production quantities likely under different production rates for individual leases along two main river estuaries. Unfortunately, it is not possible to provide information on monetary losses when closures occur, since shellfish sales are registered in terms of quantity sold per lease, and market values vary greatly during the season. Thus estimates of losses are registered in terms of area (or the leased area as a percent of the total area closed).

The author continues by showing how the use of GIS in this study can help provide financial estimates of the range of losses which might be expected, or the value to the economy of production from specific estuarial areas, under different levels of productivity. For these calculations it is necessary to derive estimated monetary values for the shellfish. This can be obtained from local market sources. Knowing the point sources of pollution, it is then possible to estimate the likely value of losses along an estuary, given a lethal pollution incident at any specified point. Additionally, since the pollution point sources are classified by type, e.g. factory, pig farm, tobacco farm, sewage outfall, etc, then the maps generated of these sources allow for relationships to be established showing which type of source is generally or specifically most harmful. Remedial action can then be taken. The author concludes by showing that in

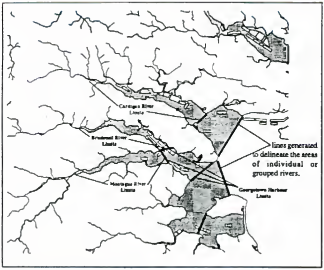


Figure 9.13 Map Showing Individual Shellfish Leases in Eastern Prince Edward Island, Canada

practice the GIS software and hardware could be expensive to purchase, and that data could also be very expensive. However, these problems could be mostly resolved if the government could make more data available in a suitable digital form, and if there was a unified policy concerning database management. At the present time there are insufficient incentives for making data more readily available.

STUDY 9.10

TITLE: "A Geographical Information System for Some Mediterranean Benthic Communities."

AUTHORS: Meaille, R. and Wald, L.

PUBLICATION AND DATE: *International J. of Geographical Information Systems.* (1990). Vol.4, No.1. pp79-86.

Table 2 - Estimated Production of Shellfish Leases in the Brudenell & Montague Rivers

Lease I.D.	Area(ha)	Estimated Production(MT) High	Medium	Low
!10001	11.36	288.44	79.04	8.74
!10002	0.31	7.87	2.18	0.24
4949	1.32	33.60	9.21	1.02
5974	1.84	46.76	12.81	1.42
M-0048	12.14	308.25	84.47	9.34
M-0052	11.75	298.37	81.76	9.06
M-0080	11.88	301.85	82.71	9.15
M-0100	11.15	283.34	77.64	8.59
M-0274A	13.36	339.29	92.97	10.29
M-0274B	7.20	183.01	50.15	5.55
M-0276	14.58	370.38	101.49	11.23
M-0285	8.73	221.79	60.77	6.72
M-0287	4.63	117.55	32.21	3.56
M-0296	10.30	261.49	71.65	7.93
M-0304	12.10	307.37	64.22	9.32
Grand Totals:				
N	15			
Sum:	132.85	3369.39	923.26	102.14
Avg:	8.84			

Figure 9.14 Example of Tabular Output from the CARIS GIS on Shellfish Leases in Prince Edward Island, Canada

Introduction/Objectives

The authors commence their study by outlining the array of problems encountered in obtaining reliable mapping information on the distribution of benthic organisms in the Mediterranean area of south east France. These problems mostly arrive from the non-standard mapping procedures which have been used in the construction of existing maps, or the obscure locations of many of the maps. In order to rectify this situation, the authors attempt to utilise a GIS in a manner which, rather than creating new layers for each marine benthic theme, attempts to synthesise the existing maps on each theme into one accurate map which is standardised amongst the new layers created. It is claimed that these new maps will have a much greater utility for any future benthic work. The physical area which the maps all cover is located on the south east French Mediterranean coast.

Methods/Equipment

All the data for each of the existing benthic community maps is referenced against a unifying map (scale 1:25 000) produced by the Institut Geographique National, which uses a Lambert III projection. This is in agreement with conventions agreed by the EC within the CORINE Programme. The mapping cell size used was 25 x 25 m^2. For various reasons the authors did not use either very old maps or very large or small scale maps when synthesizing their mapped

data. They found 26 previous maps covering the area, whose contents included in total about one hundred different classes of benthic information. They reclassified these so as to form only 25 new "standardised" classes.

Each of the 26 maps was digitised to show polygons representing any of the 25 classes of benthic community. Each map was then modified so that it fitted exactly with the reference map, i.e. by using polynomial geometrical models calculated by standard landmark correlation techniques. The authors do not say which GIS was used, but all work was done on a personal computer with data being stored in raster format on an optical disk. The authors then describe how a weighting system is used on every map. We cannot describe this in detail, but effectively, if the information on the original map is known to be good then it receives a high weighting, whereas if the mapped information is outdated, or of poor resolution, or if it is in some way questionable, then it receives a low weighting. The range of weightings is from 0 - 20. Using GIS functionality, the maps were then synthesised. Clearly, what is revealed are marine areas where there is an exact correspondence between all the weighted pixels from each map for a particular theme, and other places where there are varying degrees of difference between what is mapped. In fact the authors produce maps of conflict and maps of agreement. Figure 9.15 shows an example of mapped conflicts found in one small area near La Ciotat. Conflicts would occur where the same sea floor area recorded high weighted scores for one classification on some maps, but high weighted scores for a different classification on at least one other map. Obviously there would be some variation in the degree of conflict, and sometimes the conflict could be between more than two classes of benthic community.

Results/Discussion/Conclusions

The work undertaken in this study shows a number of quite original ways in which a GIS can be used. Firstly, the GIS has allowed for a unified and standardised set of maps to be produced for a marine area, i.e. such that comparisons could be made between the data sets, remembering that each map is showing essentially the same themes. Secondly, once the weighted maps were produced for each of the 25 themes, then each map represented essentially the "best" map of that theme. These maps could then be of value in any subsequent GIS work. Thirdly, the maps of conflict were of value in the sense that they either showed rapid benthic changes over time, or they showed areas which needed to be re-surveyed. The authors state that the scheme for weighting will need modification in the light of their experience, and they are working on the use of artificial intelligence techniques to do this.

STUDY 9.11

TITLE: "Use of a Geographical Information System for Mapping Productivity Estimates for the Mediterranean."

AUTHORS: Caddy, J.F., Refk, R. and Do Chi, T.

PUBLICATION AND DATE: *Ocean and Coastal Management*. (accepted March 8th, 1995).

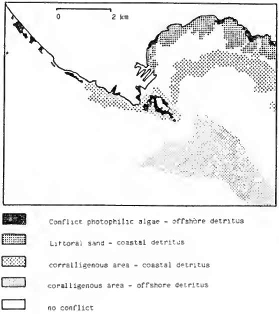


Figure 9.15 Map Showing the Greatest Conflicts Between Mapping Themes for an Area Near to La Ciotat, southern France

Introduction/Objectives

This paper re-examines recent trends in fish landings in the Mediterranean and Black sea basins, for each GFCM area, and compares estimates of production in the different basins using a measurement index of fish productivity in tonnes per surface area of continental shelf. There was a general consensus that, by the mid 1980's, fishing effort in the Mediterranean was excessive and that no significant gains in yield would result from increases in fishing effort. Thus, apart from some deep water resources, demersal stocks were seen as being exploited up to their maximum sustainable yield (MSY). Despite these contentions, subsequent increases in landings have occurred, in some cases at 100% above previous recent levels. An explanation for this was sought, and it was suggested that actual natural biomass production may be higher, i.e. due to increased nutrient enrichment from surface run-off via rivers. This was especially the case in the northern Mediterranean where human activity was much greater. This study is an attempt

to use a GIS approach to assess productivity in the Mediterranean, i.e. by examining trends in landings, spatial productivity variations and by establishing the best methods of comparing production in different basin areas.

Methods/Equipment

There were several essential sets of data which needed to be obtained. These included:

(a) Productivity per unit area for the shelf areas of the Mediterranean.
(b) Measurements of fish landings for all of the General Fisheries Council for the Mediterranean (GFCM) statistical areas during the last ten years.
(c) Maps of the shelf areas, and of the GFCM statistical areas.

Sources for this data included:

(a) The ETOP05 database (US National Geophysical Data Center) of topography and bathymetry.
(b) A map of the FAO statistical divisions of the Mediterranean and Black seas.
(c) A map of the coastal state boundaries.
(d) A map showing fishing intensity in the western Mediterranean.
(e) Landings statistics covering coastal pelagic and demersal fishes, including crustaceans and molluscs, for GFCM Area 37.

The GIS software used in this study was ARC/INFO and ERDAS GIS, running on a VAX 3400 micro-computer.

Results/Discussion/Conclusions

The authors produce several fisheries productivity maps covering the Mediterranean and Black sea regions. Figure 9.16 is one example, it giving a clear indication of catch variations in the shelf areas. In interpreting any of the maps produced, it must be borne in mind that the statistical areas used were very large, so only generalised comments could be made. Total fish production appears to be much higher in the northern Mediterranean, and the authors contend that this is due to high nutrient inflows in the north, plus only modest levels of fishing in the south. The production in some areas could have been distorted by factors such as there being mainly anadromous or freshwater species, e.g. the Sea of Azov. Pelagics appear to be particularly productive in northern sea basins such as the Adriatic and Black Seas and the Sea of Marmara. Areas of the Mediterranean which are distant from nutrient sources certainly appear to have low productivity rates. These include Sardinia, the Levant and much of the north African coast. Demersal and shellfish landings are particularly high in the Gulf of Lions and Sea of Marmara where nutrient inputs from river and land run-off would be high. The authors conclude that these increased levels of productivity are interesting and are worthy of a more detailed study at the sub-regional level, i.e. with a view to either proving their hypothesis relating to nutrient inputs and their effects, or to allow new hypotheses to be formulated.

Figure 9.16 Total Catch of Pelagic and Demersal Fishes for 1989 from all Shelf Areas of the Mediterranean

STUDY 9.12

TITLE: "Torres Strait Marine Geographic Information System".

AUTHORS: Long, B., Skewes, T. and Poiner, I.

PUBLICATION AND DATE: *Recent Advances in Marine Science and Technology '94*. (Eds. O. Bellwood, H. Choat and N. Saxena) (1994b). Pacon International, Hawaii, USA. pp231-239.

Introduction/Objectives

The Torres Strait is a shallow marine shelf area which links the Coral Sea in the east to the Arafura Sea in the west, Papua New Guinea to the north and Queensland, Australia to the south. It has a complex bathymetry, and there are over 700 reefs, shoals, and some 300 islands, most of which are remnants of hill tops which were once part of the land bridge from Australia to

New Guinea. A diverse resource management structure has evolved in the area, involving the division of the marine shelf into zones which are variously managed by the Queensland State, the Australian Commonwealth and the Government of Papua New Guinea.

Methods/Equipment

In order to help with this management a Torres Strait GIS was set up in 1993, which is managed by the Australian Fisheries Management Authority (AFMA) from both Canberra and Thursday Island. A variety of ways and sources were used to acquire data for the GIS, ranging from purchasing digital datasets, to in house digitising and the entry of geo-referenced research data from various reports. Table 9.4 shows the data sets which were held by 1994. The base maps were digitised from 1:100 000 topographic charts of the Torres Strait. A number of GIS techniques were used to create area maps for some of the continuous variables, e.g. seagrass, sediment type and bathymetry. The software used was SPANS GIS, running on a PC and using the OS/2 operating system.

Results/Discussion/Conclusions

The Torres Strait GIS has been used to produce a large array of maps covering many topics. In their paper the authors give details on two of these:

(a) Seagrass Dieback Survey. The objectives of this survey were to quantify and assess the magnitude and extent of a reported seagrass decline in the north-western Torres Strait, i.e. by comparing data gained between 1984-1989 to data gained in 1993. Data on the present distribution of seagrass was gained by SCUBA divers who visually quantified estimates of seagrass ground cover at 251 sampling sites randomly spread throughout the 4743 km^2 study area. A GPS was used to determine geo-reference points. Data was also gathered on substratum, epibenthos, water visibility (m) and water depth (m). Maps were produced which showed the historical distribution (Figure 9.17a) and the present distribution (Figure 9.17b) of seagrass, and from these it was possible to construct a third map (Figure 9.18) which showed the extent of the changes in seagrass distribution. Figure 9.18 was constructed using the triangulated irregular network (TIN) algorithm within SPANS GIS. The authors cautioned that, although it was obvious that major changes had occurred, the interpretation of the maps should proceed cautiously in view of the reliability level of the data and the methods used. At least the basis had been provided for management decisions on what to do about seagrass dieback.

(b) A dugong sanctuary. The dugong population in the Torres Strait is the largest in Australia and possibly the world. These mammals are susceptible to overfishing because of their restricted stock and low reproductive rate. Additionally, they form an important dietary component for Torres Strait islanders. A dugong sanctuary has been formed in the western part of the Strait. The GIS has proved effective in showing whether dugong are currently dispersed in areas which offer the best habitats, and whether they are in areas which are least likely to be subject to human predation. In fact the GIS will allow for a means of modelling the complex interactions between biological factors, preferred habitats, physical factors, sociological factors, etc, thus allowing for the most effective dugong management plan to be implemented. It is clear from an

Table 9.4 A Brief Description of the Datasets Currently Held in the Torres Strait GIS (from Long et al, 1994b)

	Description	Data Type	No. attrib.	No. records	Data Sources
1.	Islander community information; population census demographics and traditional fishing catch data	point	30	12	Australian 1986 census data, Harris et al. (1994)
2.	Water depth	point	1	>20,000	Australian nautical charts: Aus 376, Aus 301, Aus 700, Aus 840, Aus 839, Aus 296, Aus 289, Aus 294, Aus 292, Aus 293, Aus 299, Various: pearlshell survey (Colgan end Reichelt, 1991), seagrass surveys (Long and Poiner, 1993), rock lobster surveys (Pitcher et al, 1992*a*)
3.	Sediment grain size data	point	7	251	Verious CSIRO cruises (Long and Poiner, 1993); University of Sydney reports (Harris, 1988)
4.	Rock lobster *(Panulirus ornatus)* abundance	point	4	370	CSIRO rock lobster survey (Pitcher et el., 1992*b*)
5.	Pearlshell *(Pinctada maxima)* abundance	point	4	370	CSIRO rock lobster survey (Pitcher et al., 1992*b*)
6.	Epibenthos and bottom type descriptions	point	4	370	CSIRO rock lobster survey (Pitcher et al., 1992*b*)
7.	Pearlshell *(Pinctada maxima)* abundance from pearl bed surveys	point	6	67	Colgan and Reichelt (1991)
8.	Trochus *(T. niloticus)* abundance (Bourke Isles, eastern Torres Strait)	point	1	80	CSIRO trochus survey (Long et al., 1993)
9.	Reef slope bottom cover (%)	point	4	80	CSIRO trochus survey (Long et al., 1993)
10.	Seagrass presence/absence data	point	1	1020	Various CSIRO cruises (Long end Poiner,1993; Pitcher et al., 1992*a*; Poiner and Harris, 1993)
11.	Seagrass quantitative data: seagrass and algae species, no shoots/m, above and below ground biomass	point	34	2600	Various CSIRO cruises (Long end Poiner, 1993)
12.	Dugong abundance: aerial survey	point	1	380	Marsh and Saalfeld (1991)
13.	Trawl species catch abundance and weight	point	16	80	Poiner and Harris (1993)
14.	Prawn log-book catch data	point	16		Queensland DPI (C. Turnbull)
15.	Shipping lenes through Torres Strait	line	2	2	digitised from nautical charts
16.	Australian and Papua New Guinea mainland	area	3	2	digitised from 1:100,000 topographic maps
17.	Torres Strait islands	area	3	>300	digitised from 1:100,000 topographic maps
18.	Torres Strait reefs	area	3	>700	digitised from 1:100,000 topographic maps
19.	Dugong sanctuary	aree	3	1	Johannes and MacFarlane (1991)
20	Islander marine tenures	area	3	9	Johannes and MacFarlane (1991)
21.	Area of the prawn fishery	area	3	1	Queensland Government gazette
22.	Permanent closure of the prawn fishery	area	3	1	Queensland Government gazette
23	Exclusion area of prawn fishery for reporting purposes	aree	3	1	Queensland Government gazette
24	Area of the tropical rock lobster fishery	area	3	1	Commonwealth Government gazette
25	Area for the pearl shell fishery	erea	3	1	Commonwealth Government gazette
26	Area for the turtle fishery	area	3	1	Commonwealth Government gazette
27	Area for the dugong fishery	area	3	1	Commonwealth Government gazette
28.	Area of the Spanish mackerel fishery	area	3	1	Commonwealth Government gezette

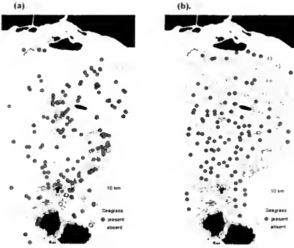


Figure 9.17 Seagrass Presence or Absence Data In Torres Strait from (a) the Historical Survey (1984/89) and (b) the 1993 Survey

inspection of Figure 9.19 that the dugong sanctuary area is not in the best location vis a vis their present distribution, i.e. one which accords more closely to the actual distribution of their seagrass food source.

STUDY 9.13

TITLE: "Development of an Integrated Marine Geographic Information System."

AUTHORS: Li, R. and Saxena, N.K.

PUBLICATION AND DATE: *J. of Marine Geodesy*. 1993. Vol.16. pp293-307.

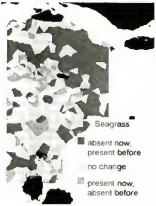


Figure 9.18 Changes in Seagrass Distribution in Torres Strait Between 1984/89 and 1993

Introduction/Objectives

The authors commence their study with a review of the increasing range of topics to which digital marine acoustic data is now being applied, e.g. in the fields of not only bathymetric mapping but also in the interpretation of sea bed types, sediment movement analysis, resource assessment, pipeline and cable routing and other geophysical and oceanographic work. To help in this applications work, the Pacific Mapping Center, at the University of Hawaii, have developed a marine GIS (MGIS) which has a large range of capabilities, only some of which can be examined in this case study. The essential feature that makes the MGIS different from the usual GIS is that the MGIS should be able to integrate side-scan sonar digital data in a similar way that a GIS can integrate RS data. The main purposes for developing their MGSI was as an aid in the selection of deep water research sites, for the generation of a 3-D database for navigation, to simulate underwater operations of a submarine research vehicle and for the production of mapping data.

Methods/Equipment

In designing the MGIS, the authors took into account the following main points:

a) The hardware configuration should be an open system for installing most relevant popular software.

Figure 9.19 Seagrass and Dugong Distribution in the Torres Strait Plus Location of the Dugong Sanctuary

b) Various software packages should be capable of being integrated into the MGIS.
c) The system should be easily capable of expansion.
d) 3-D data structures and modeling functionalities should be included for the simulation and animation of marine operations.

The MGIS hardware configuration which was set up at the University of Hawaii (Figure 9.20) is fairly comprehensive. Its main features are:

(i) Two work stations and two PC's running three operating systems.
(ii) A GRINNEL image processing system to handle the digital sonar image processing.
(iii) Connections via an Ethernet to other computer components on the campus.
(iv) A Silicon Graphics Iris workstation for animation purposes.
(v) Connections via Internet to off campus sites.
(vi) An array of peripherals including monitors, tape storage and drives, plotters, scanners, printers, etc.
(vii) A VAX work station to handle a variety of image and data processing functions. To make the handling of these as user friendly as possible, a task oriented menu has been constructed.

(viii) S SUN SPARC workstation having ARC/INFO installed plus programmes for format conversions and data integration.

Obviously, other systems are available for integration into the MGIS since the basic configuration as shown (Figure 9.20) is connected to other parts of the campus.

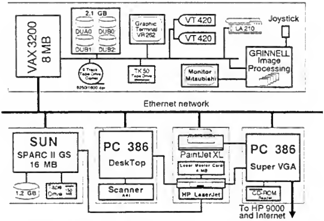


Figure 9.20 **Hardware Configuration of the Marine Geographic Information System at the University of Hawaii**

Since there is such a variety of potential data which could be integrated by the MGIS, the authors describe the main categories of spatially referenced data which could be most useful. This includes bathymetric data acquired from single-beam or multibeam acoustic systems, or sea floor imagery acquired from either side scanning systems or from video equipment. Other data may be available from marine mining maps, marine seismic data, gravity data and magnetic data. Data on other parameters which are unrelated to bottom characteristics could also be integrated into the MGIS, e.g. sea surface temperature data, wave height data and any data relating to spatial distributions at the surface.

The authors describe in some detail the methods used to select a deep-water marine research site. The idea was to find a site having a flat bed, which was as close as possible to a shore base, and which could therefore be conveniently used for underwater research experiments and developments. A 3-D bathymetric model was developed (Figure 9.21) using two series of previously acquired multibeam bathymetric data as surveyed by NOAA. These data were used to calculate parameters relating to both x and y directions and to depths. This allowed slope angles to be calculated. A small area to the south west of Hawaii was eventually found as being best suited to the search criteria.

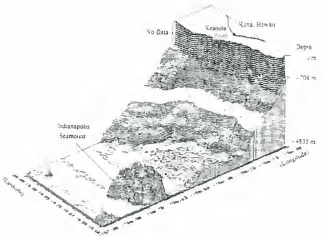


Figure 9.21 Display of Contours in the Selected Deep Water Site Off the Island of Hawaii

Results/Discussion/Conclusions

Once any bathymetric model has been obtained using the MGIS, then it is possible to view it from any direction, to zoom in or out, to colour code different depths and, if the requisite sonar imagery is available, then it is possible to drape the 3-D model with either geological information or perhaps with sediment type information. Further types of analyses are also being envisaged. Thus the authors note that "An analysis of layers of bathymetry, magnetic data, sonar images, and temperature gradients in areas with a high fishing productivity can help in understanding the relationship between fish habitats and the corresponding marine environment, This may improve our capability to balance between protecting marine species and increasing and maintaining fishing productivity." (p.302).

STUDY 9.14

TITLE: "Environmental Risk Analysis of Salvaging the Irving Whale."

AUTHORS: Collins, N. and Hurlbut, S.

PUBLICATION AND DATE: *Paper Presented at GIS93*; March 23-25, 1993, Ottawa, Canada.

Introduction/Objectives

On September 7th, 1970 an oil barge carrying some 4270 tonnes of Bunker C oil, sank in the Gulf of St. Lawrence, Canada. At the time only a small amount of the oil escaped, since it was of a type which increasingly solidifies in colder water, and the temperature at the 70 metre depth of the vessel was only just above freezing. Over the two weeks following the sinking, the leaked solidified oil was carried by prevailing winds along the paths shown in Figure 9.22. By September 21st, some 200 tonnes of oil was polluting 32 kilometres of shoreline on the Iles de la Madeleine, and a small amount was found on the shores of Cape Breton Island. Since the oil becomes solidified it is fairly easily disposed of, though it does have a high nuisance value, especially since small amounts are continuing, some 20 years later, to leak from the barge.

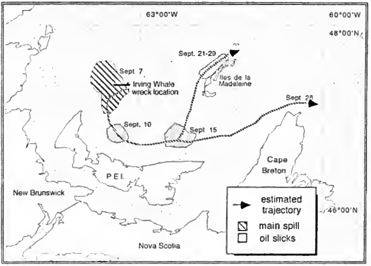


Figure 9.22 Estimated Oil Trajectories from the Oil Spill Coming from the Irving Whale in the Gulf of St. Lawrence

In response to public concern the authorities have initiated studies of salvage options, including the environmental risks involved. Most concern has come from the fishing community on Prince Edward Island, since they consider it likely that the remaining 3100 tonnes on board will pose a threat to their livelihoods for many years to come. A consortium of companies has now reviewed and reported on:

(a) The information surrounding the initial sinking of the barge and the subsequent impacts of continued oil leakage.

(b) The major resources vulnerable to a spill from any of the remaining oil.

(c) The marine and shoreline areas most likely to be oiled.
(d) The magnitude of the impacts anticipated.
GIS methods have been used to help in these reports.

Methods/Equipment

Obtaining the data concerning the distributions of some of the variables which needed to be mapped as part of this study was relatively easy, e.g. data on recreational areas, seal colonies and sea bird distributions, but data concerning fish distributions and fishery areas was not so well documented, and it was liable to temporal variations. A major task then was to identify offshore fishing areas and to establish up-to-date patterns of fishing activity. Information on these were used in the GIS so as to describe the relative importance of different offshore areas to surrounding communities. The GIS software used was "Atlas Pro for the Macintosh". Once the GIS had been used to establish the distribution of fishing activity, the data was transferred to OILMAP, an oil spill modelling application to provide a single resource sensitivity and trajectory modelling database. Further details on both of these software packages are given in the source document.

Details on fish catches for all of 1991 were obtained from both fishing vessel logs and from purchase slips documenting the type and volume of fish sold to commercial buyers. Records of all fishing vessel logs, which includes geo-referenced catch locations, are kept at the Statistical District for Fisheries and Oceans Canada (DFO) in Moncton, New Brunswick, and details on landings are kept by the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia. Data from the DFO was obtained on a 9-track digital tape, and the authors explain in detail how the catch data was transformed via a specially written Fortran programme so that it was in a suitable format for use by the GIS. A summary file of total catch by species group for each unit area by Statistical District was produced and downloaded to a Macintosh computer. The digitised boundaries of all the fisheries areas (and the coastline) were loaded to the GIS, and it was then a simple task to produce output such as that shown in Figure 9.23. Similar maps for all the Gulf of St. Lawrence fisheries were compiled, both by total catches, by species and by season.

Results/Discussion/Conclusions

The final analysis indicated that all demersal fisheries were concentrated in similar areas regardless of species. These areas were not within the zones of high risk from further oil leakages from the Irving Whale. Similarly, the semi-pelagic redfish and shrimp fisheries were also concentrated into areas where the risk was minimal. The authors conclude by noting that the availability of geo-referenced data was invaluable to this study, though they suggest ways in which data recording could be further improved, e.g. by having translation capabilities for converting different geo-referencing procedures. Also, it is essential that a greater awareness is made of the data bases that exist as potential input sources to any GIS.

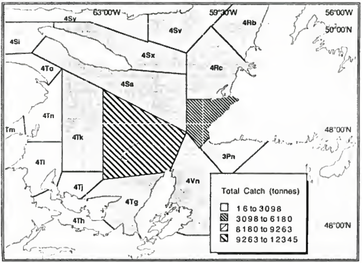


Figure 9.23 The Origins of all Catches Landed on Iles de la Madeleine During 1991

STUDY 9.15

TITLE: "Protecting Irish Interests: GIS on Patrol".

AUTHOR: Pollitt, M.

PUBLICATION AND DATE: *GIS Europe*. (1994) Vol.3, No.6. pp18-20.

Introduction/Objectives

With the extension of Ireland's exclusive fishing zone to 200 miles in 1976, it meant that the country assumed responsibility for controlling fishing activities in 137 000 square miles of relatively rich fishing grounds. Most of the fishery patrol activities are carried out by the Irish Navy using seven ships plus some helicopters. Faced with an increased work load, fishery protection work is now being computerised, with the introduction of relational databases, expert systems and a GIS. A fully integrated Fishery Protection Information System (FPIS) has been set up which provides officers with operational information, and a fishery protection database records details of all fishing vessels operating in Irish waters.

Methods/Equipment

Each fisheries patrol vessel is equipped with a UNIX server, local area network and PC's. Databases are regularly updated from land to ship using satellite communications. Each fishery protection vessel must have access to complex and up-to-date fishery law. A PC-based expert system was developed to standardise the Navy's knowledge and enforcement of fisheries legislation. This contains a library of fisheries law alongside a "knowledge base" of common implementation rules. Before 1992 there was no way of achieving visual output from the FPIS so, in order to relate text based information to actual locations, to plan where patrols ought to be looking at fishing trends, and to allow all fishing activity, trends and incidents to be viewed, a GIS was introduced.

The GIS development, based on ARC/INFO, was instigated at the Naval Computer Centre in Cork, Ireland. The graphical side is based on digital displays of navigational charts. The Irish straight baseline 3, 6, 12 and 200 mile fishing limits, as well as the limits in nearby countries, have been superimposed on the charts. Other attributes added to the system include the ICES grid system, the Irish Box, disputed fishing limits, spawning grounds, fishing rights, underwater cables and pipelines, offshore platforms, low tide lines, navigation aids and submarine exercise areas. Figure 9.24 gives an example of GIS output, showing which countries (colour coded) have rights to fish for certain species within the 6-12 mile fishery zone.

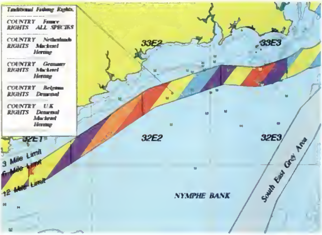


Figure 9.24 Example Output from the Irish Navy's Fishery Protection GIS Showing Fishing Rights of Neighbouring Countries

Results/Discussion/Conclusions

The system has been operational since December, 1992. In the fisheries protection headquarters all GIS output can be visually displayed on a chart wall so that briefing sessions can be run. Any part of the huge fishery area can be zoomed into and any reported fishing activity can then be reviewed. The location of all vessels can be displayed as colour coded icons. Interactive querying can be accommodated with the user selecting activities of interest from a set of predefined attributes, e.g. by nationality, fish species, vessel type, method of fishing, licence information, etc.

According to the people entrusted with using the system it is both very useful and highly efficient. It allows for the optimum allocation of scarce resources. It also allows for a careful check to be made on vessels which have in the past made infringements. In the near future it is planned that the GIS capability should be installed on each individual patrol vessel. It is also anticipated that extra duties will be able to be incorporated within the same overall system, e.g. pollution control and monitoring, search and rescue operations and any real time tracking. Eventually a total coastal management concept is envisaged, including the tracking of all sea-going activities.

STUDY 9.16

TITLE:	"Note on the Sediments and Hydrology of the Gulf of Carpentaria, Australia."
AUTHORS:	Somers, I.F. and Long, B.G.
PUBLICATION AND DATE:	*Australian J. of Marine and Freshwater Research.* (1994) Vol.45, pp283-291.

Introduction/Objectives

The Gulf of Carpentaria is a large embayment on the north east of Australia's coastline. It has an area of over 500 000 km^2 and a maximum depth of only 70 metres. The region has a monsoon climate with rainfall occurring mainly between December and March. The Gulf supports several important fisheries including one for penaeid prawns and a developing trawl fishery for teleosts. In November-December 1990, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Division of Fisheries, conducted a gulf-wide research cruise in waters mainly deeper than 20 metres. The main objectives of the cruise were to describe the size and distributions of fish resources, though information on sediments and water properties was also collected, i.e. to help in understanding the reasons for species distributions. This paper only describes results relative to hydrographic and climatic data.

Methods/Equipment

Figure 9.25 shows several features of the survey:

(a) The open circles show the locations of the main sampling points. These were established on a systematic grid, with a distance of 30 nautical miles between points, which themselves were fixed using a global positioning system.
(b) The land based open squares show the location of four Australian Meteorological Stations from where climatological data was obtained. Thus information on rainfall, temperature, wind speed and direction and atmospheric pressure was collected for the period 1968 to 1991, and were collated to monthly means.
(c) The line marked "T" shows a transect used to describe a north-south profile of the gulf.
(d) The solid black circles show additional sediment sampling points. Sediment data from these points had been collected opportunistically by another research vessel, plus other assorted means. The authors provide details on how the sediments were sorted by different granular fractions.

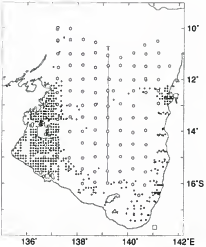


Figure 9.25 The Main Features of a Gulf of Carpentaria Marine Survey (see text for details)

Temperature and salinity data were recorded at each main survey point using a Yeo-Kal Model 606 data logger. Surface, mid-water and bottom water samples were taken in order to measure turbidity. Having gathered all the data, spatial analyses were performed using SPANS GIS

software running on a PC, with the main maps being derived from using the interpolation functions to derive sediment and water temperature "contours".

Results/Discussion/Conclusions

The authors showed the results from the climatological data collection, but we need not discuss these further. Surface water temperatures showed very little horizontal stratification throughout the Gulf. However, there was a striking vertical stratification in deeper waters, and this difference between surface and bottom temperatures can be seen in Figure 9.26. Salinity showed no vertical stratification and only slight horizontal stratification. Turbidity was generally very low throughout the Gulf. Sediments were almost exclusively of mud and sand, with less than 6% of samples having a gravel content of more than 20%. Conditions generally became "muddier" from south-east towards the north-west. Muds were also very noticeable around sheltered embayments and river outlets.

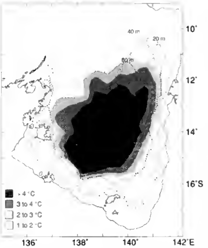


Figure 9.26 Differences Between Surface and Bottom Water Temperatures in the Gulf of Carpentaria, Nov/Dec 1990

The authors conclude by noting the importance of understanding the relationships between the various physical parameters measured and the productivity and distribution of the marine fauna. They show the speculation which has gone on over the evolution of the Gulf, and point out that since it must be a relatively new marine feature, then processes of faunal colonisation will still be occurring. It is speculated that the strong vertical temperature gradient in the central Gulf

results from its depth and sheltered position, and that sediment accumulations of finer particles in the north west areas are largely the result of the clockwise current circulation. In the Gulf there is a strong link between sediment texture and the biomass and species diversity of benthic organisms, with abundance and diversity being much higher in the south-east where sediments were generally coarser. In fact, sediment grain size, together with depth, was found to explain most of the spatial variation in abundance of the various commercial penaeids in the Gulf.

STUDY 9.17

TITLE: "Ecological and Oceanographic Relationships in the Southern Ocean."

AUTHORS: Trathan, P., Murphy, E., Symon, C. and Rodhouse, P.

PUBLICATION AND DATE: *GIS Europe*. (1993) Vol.2, No.6. pp34-36.

Introduction/Objectives

The Marine Life Science Division of the British Antarctic Survey (BAS) has been gathering data for the past 15 years relating to various oceanographic and biological processes which occur within the Southern Ocean ecosystems. Most of the data has been gathered from shipboard surveys, but increasingly satellite data is also being obtained. The use of satellite data is proving to help in the analysis of large scale environmental processes operating in the area. The use of GIS has only recently commenced as a tool for integrating the various data types. The main focus for the research effort has been the Scotia Sea, whose location is shown in Figure 9.27. This area is the site for some major fisheries, especially for Antarctic krill (Euphausia superba).

Methods/Equipment

To fully appreciate the interactions between physical and biological components in the Southern Ocean area, it is necessary to collect data at a number of temporal and spatial scales. At the micro scale, which may be measured in square metres and minutes, work is being carried out on processes such as the grazing rates of zoo-plankton communities. At the meso scale activity includes the investigation of relationships between plankton concentrations and gyres, upwellings or ocean fronts. By contrast, at the macro scale, which may cover thousands of kilometres and several years, studies are being made on variations in the ice fronts or ocean current positions. GIS is gradually being introduced at all scales, and for many studies its scale independence is proving to be of great value.

Much of the data required is already in existence. Coastline data has been digitised and bathymetric digital data is available as part of the General Bathymetric Chart of the Oceans (GEBCO) and from research cruises undertaken by the BAS Geosciences Division. The main

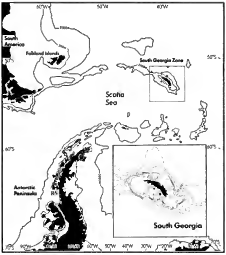


Figure 9.27 Location Map of the Scotia Sea Area, Including the South Georgia Island Area in Detail

remotely sensed data being used at present are that on sea surface temperature and sea ice extent. This data is obtained from US National Oceanographic and Atmospheric Administration (NOAA) satellite images. These data are of use in inferring oceanographic conditions and in estimating the distribution of many Southern Ocean animals. Eventually it is proposed to use ocean colour satellite data. Biological data comes mainly from fisheries and other surveys indicating distributions and abundance. Some information has recently been obtained from monitored tagging experiments. Catch rates and location data are available for all exploited fish stocks in the Southern Ocean.

Results/Discussion/Conclusions

At the present time most GIS work is being done on examining the relationship between physical parameters and the distribution of different species. Krill is being extensively studied because it is immediately available in the food chain to an array of higher predators. Figure 9.28 gives an indication of krill density along survey tracks in the large cell surrounding South Georgia (see Figure 9.27). Since it is known that krill biomass volumes are now very low, then it is important to be able to calculate both the causes and effects of this. Plans for the immediate future include gathering more detailed data on fin fish and squid distributions, as well as using satellite tracking methods to learn more on the disposition of seals and birds. Finally, the authors see this

Southern Ocean GIS as being useful for establishing the causal links between oceanographic or meteorological phenomena and/or events occurring at one area, which prove to have a long term knock-on effect in other areas.

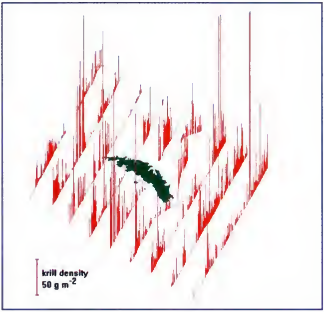


Figure 9.28 Krill Biomass Distribution in the South Georgia Area as Plotted by the British Antarctic Survey

STUDY 9.18

TITLE: "An Efficient Method for Estimating Seagrass Biomass."

AUTHORS: Long, B.G., Skewes, T.D. and Poiner, I.R.

PUBLICATION AND DATE: *Aquatic Botany*. (1994a). Vol.47. pp277-291.

Introduction/Objectives

Seagrasses are an important component of coastal ecosystems. They provide nursery grounds, adult habitat and food for commercially important species, plus habitats for a range of marine birds and mammals. They also produce large amounts of detritus and dissolved organic matter. However, the traditional method for sampling seagrass, by taking cores and by quadrats and perhaps the use of scuba divers, is time consuming and expensive. This limits the amount of sampling which can be undertaken, which in turn can result in less reliable estimates. The authors have developed a sampling technique for seagrass biomass estimation which uses aerial photography, GIS and global positioning systems (GPS). A seagrass grab was also used. The area of study for the authors sampling survey covered 38 km^2 at the mouth of the Brisbane River in southern Queensland, Australia.

Methods/Equipment

A digital outline of part of the study was obtained from the Port of Brisbane Authority, and the rest of the study area was digitised from local 1:25 000 topographic maps. The digital outlines were input into a PC version of SPANS GIS. Figure 9.29 shows the study area used plus the

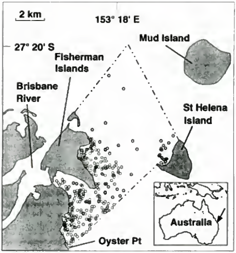


Figure 9.29 Map of the Seagrass Sampling Area in Moreton Bay, Queensland Showing Distribution of Sampling Points

location of seagrass sampling points. Using an aerial photograph of the study area, taken at low tide from a height of 3 000 metres, six seagrass and one subtidal (channel) strata were identified. The outlines of these areas were also digitised for entry to the GIS, and Figure 9.30 shows the various classifications. The GIS was then used to both calculate the area of each of the seven strata, and as a basis upon which to divide up the area so that random seagrass sampling points could be located.

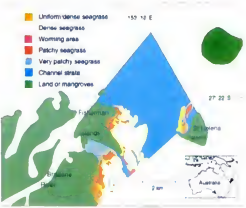


Figure 9.30 The Classification of Various Seagrass Strata in Part of Moreton Bay, Queensland

In the field the selected sampling points were detected using the GPS. At each site a sample of the bottom was taken using a hand operated seagrass grab. The authors detail the specifications of the grab and how it was used. The contents of each "grabbed" sample was sorted (at sea in a dinghy), with the seagrass and rhizomes (roots) being removed for later sorting by species, drying and weighing. A record was made at each sampling point of the sediment texture. The authors were careful to standardise the seagrass grabbing techniques, i.e. so that differences in results could not be caused by differences in the digging efficiency of the grab working in different types of bottom conditions. A detailed description was also given on how the authors worked out where best, among and between, the seven strata their sampling efforts should be directed (based on a Neymann allocation model), on the optimum number of grabs which should be taken per site from a cost-effective viewpoint, and on how many samples would be required. Thus they estimated that a total of 361 samples were needed to be within a precision of 15%.

Results/Discussion/Conclusions

Four types of seagrass were found in the study area. The distribution of these was a reflection of the varying conditions found, with water depth being the main determinant. There was a

strong correlation between the above and below ground seagrass biomass density, though the proportions of biomass above or below ground varied between the species. There was no seagrass in the so-called "channel" stratum, whilst the highest amount was found in the St. Helena stratum (80%). The authors provide several detailed tables showing various parameters relative to seagrass distribution and density.

The study showed that cost-effective, accurate and reliable seagrass biomass estimates for the study area could be achieved by using the combination of aerial photograph, GIS, GPS and the seagrass grab. Stratification of the study area substantially improved the precision of the estimate compared with a simple random sample. The grab proved an easier method of obtaining samples than the traditional coring method, though some modification to its design is necessary unless some allowance is still to be made for variations in bottom type (and thus grab penetration). The authors also found that, whereas many traditional studies of seagrass biomass had relied upon counting the numbers of shoots to obtain a measure of density, a reliable estimate could be found by simply weighing the biomass.

STUDY 9.19

TITLE: "A simulated GIS exercise to demonstrate its usefulness in the management of Senegalese demersal fisheries."

AUTHORS: FAO-CRODT-ORSTOM.

PUBLICATION AND DATE: *Report of the Training Course on the Application of GIS to Fisheries*. FAO Project GCP/RAF/288/FRA. (Rabat, Morocco; 3-14 April, 1995)

Introduction/Objectives

To achieve a sustainable fisheries sector in West African waters, it will be necessary to improve the range and quality of information which is available to fisheries management in order to ensure effective decision making. As one means of achieving this, a regional GIS for coastal and oceanic marine fisheries is being established for West Africa, as a collaborative venture between FAO and the respective governments. This covers most West African maritime countries. The establishment of this GIS will involve not only the training of personnel in the practical use of GIS, but also in creating an awareness amongst the decision-makers as to the potential which GIS can offer for management and development planning. Although the GIS will eventually operate at a variety of scales ranging from local to international, it will be initially important to develop fisheries resources GIS's at a national level. The reasons for this are mainly concerned with minimising problems associated with obtaining standardised data, with exchanging data and with creating a local impetus for the GIS to succeed.

As part of the promotion of the fisheries management GIS, a training course was organised by FAO, in collaboration with the Royal Centre for Remote Sensing (Rabat, Morocco), the

Scientific Institute of Marine Fisheries (Casablanca), the Oceanographic Research Centre of Dakar-Thiaroye (CRODT)(Senegal), and the French Institute of Scientific Research for Development and Cooperation (ORSTOM)(France). This was held in Rabat, Morocco in April, 1995, and the main purpose was to introduce key personnel to the functionality and potential of GIS as an aid to fisheries management. As part of the training course, FAO together with CRODT and ORSTOM, developed a GIS simulation package whose aim was to both illustrate the main GIS concepts, methods and the results that can be achieved and to explain any functional constraints which the system has.

The simulation package consisted of three "case studies":

(a) To show the relationship between the distribution of demersal fish resources in Senegal and factors relating to fish habitats.

(b) To show the seasonal conflicts which occur on a local scale during the May-June period between artisanal fishermen from Saint Louis, who are fishing for "sole" with gill-nets, and those from Kayar, who are fishing for "thiof" using hand lines.

(c) To show the increasing conflicts which are also occurring, though here at a national scale, between artisanal fishermen and the industrial fishing fleet.

The simulation package has not been written in great detail since it was only for demonstration purposes. Arising from the demonstration of each of the case studies, participants in the training course should be aware of the types of "on demand" mapping output which could be produced, the types of tabular data involved, and they should also have gained an appreciation of the amount of support which GIS can offer to those management problems having a spatial component.

Methods/Equipment

The simulation package was assembled at the FAO headquarters in Rome. To do this data had to be acquired from a number of sources including ORSTOM, the CRODT and UNEP. The data supplied was in a mixed format consisting of both paper and digital maps and tables. All work was done on PC's using four main software packages, i.e. FoxPro (as a database) and IDRISI, PC ArcView and ArcInfo (for the GIS graphical work). In assembling the material problems had to be overcome concerning different map scales, different coordinate systems, units of measurement, incorrect geo-references, missing data, types of data, etc. For demonstration purposes, the GIS output was assembled as a presentation display. Thus it was necessary to put together a computer based "presentation" consisting of a complete sequence of screen views which were specially selected to show how a GIS is assembled in order to carry out a particular task. FAO also prepared a manual which described textually the operations of each of the three case studies.

Results/Discussion/Conclusions

Although three case studies were presented at the training workshop, space precludes an illustration of all of these. Only the resulting presentation of case study (a) above is described

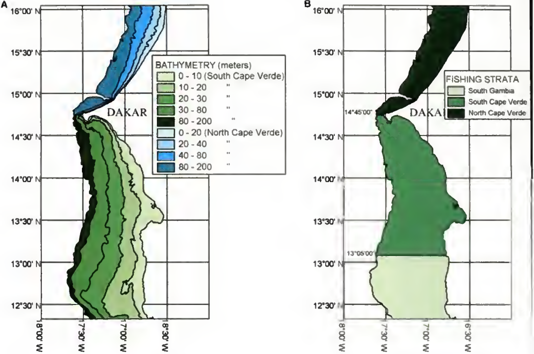
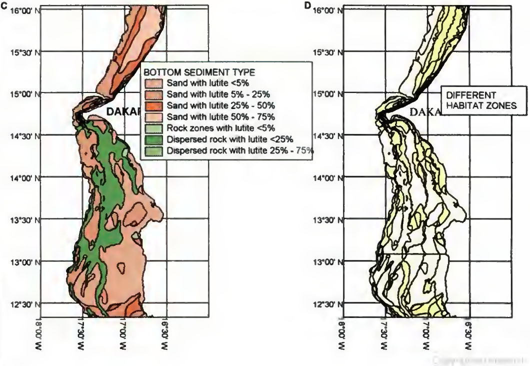


Figure 9.31 Series of Simulated GIS Output to Show the Possible Relationship Between Fish Distribution and Habitats in Senegalese Waters (to be continued)



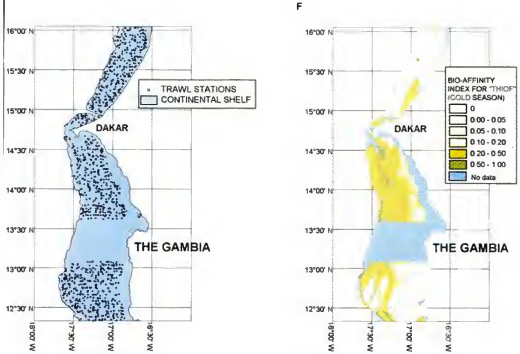
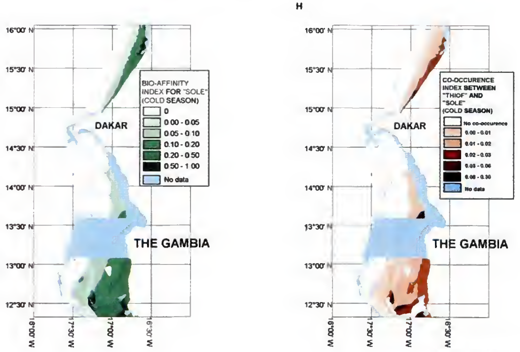


Figure 9.31 (Continuation)



in some detail. Figure 9.31 shows the sequence of maps which were displayed as a means ofshowing the relationship between fish resources and their habitats, and this sequence is now briefly described.

1. A bathymetric map using five class intervals was digitised using data from a series of 1:200 000 paper maps provided by ORSTOM. This covered the inshore Senegalese waters to a depth of 200 metres, i.e. to approximately co-incide with the continental shelf area (Figure 9.31a).

2. In the absence of sufficient data on bottom water temperatures, a "proxy" strata map was produced with the idea of showing how water temperatures were likely to change with latitudinal variation from north to south (Figure 9.31b).

3. Using the same data source as in 1 above, a bottom sediment type map was digitised. This effectively classified the shelf waters into seven classes each of which was differentiated by particle size and/or the degree of "rockiness" (Figure 9.31c).

4. The three maps described above were superimposed (overlayed) so as to produce a marine fish "Habitat" map for Senegal (Figure 9.31d). In carrying out this operation, the computer also generates a new attribute table which contains the details on all three maps. From a perusal of Figure 9.31d it can be seen that a large number of different habitat polygons have been produced, and it is possible to perform various calculations or analyses of these as required. No key has been shown on Figure 9.31d because of the large number of different classes, but the necessary information is stored in associated attribute tables.

5. In order to show the distribution of fish resources, it was necessary to use a Senegalese government database holding containing data on trawl surveys. The type of data which is relevant to this exercise included:

Season 1	cold season
" 2	warm season
Code	a code for the trawl station
Latitude	a geo-reference
Longitude	a geo-reference
Trawl time	duration of trawl
Species	names of species caught
Weight	for each species caught

For ease and uniformity of use this data was transferred from its original ASCII file format into the database package called FoxPro.

6. Using this trawl survey data, it was simple to generate another map layer called "Trawl Stations" (Figure 9.31e). Here this is shown as the basic locations of the trawl stations, but it must be remembered that for each of these sites it would be possible to show the quantity of each species of fish caught, by warm or cold season if required.

7. By overlaying the trawl station sites onto the habitat map it was possible to determine the relationship between fish types and habitat, i.e. since fish types are recorded at all trawl station sites. Clearly it would be difficult to produce map output on this spatial relationship - this is mainly because of the large number of possible relationship classes. However, this overlay procedure was useful in that it produced a new attribute table listing the relationships, and this table provided the information for the next step, i.e. to produce a bio-affinity index. This represents an index showing the degree of relationship between a species and a habitat type.

8. The bio-affinity index was computed for each trawl station using the formula

$$\frac{X/\Sigma(X)}{\mathrm{Max}[X/\Sigma(X)]}$$

where $X = [\log(1 + \text{catch rate})]$

An average species bio-affinity index was then computed for each season and for each polygon of the habitat coverage map.

9. Using the attributes contained in the bio-affinity index file, it was possible to link these to the habitat map coverage in order to produce a geographic representation of the bio-affinity index for each species and for either the warm or cold season. Figure 9.31f shows the bio-affinity index map for "thiof" in the cold season, and Figure 9.31g shows a similar map for the distribution of "sole".

10. Finally it was possible to produce a map showing the co-occurrence between thiof and sole, i.e. by simply overlaying Figure 9.31f with 9.31g to produce 9.31h. Note that in the majority of the Senegalese continental area there was in fact little co-occurrence. This map should give the fisheries manager a fairly clear visual impression of habitat preferences for the main fishery species in Senegalese waters.

We have described here only one specific task which was used as part of the GIS training programme. The other two case studies detailed various other ways in which GIS might be useful. So, for instance, it would be a comparatively simple task for the GIS to use the trawl survey data to calculate an abundance index by species and by trawl station. This data could then form the basis of an interpolation mapping exercise to produce mean fish density maps for Senegalese waters by season and by species. A knowledge of fish density would greatly help in the allocation of fishing effort and in estimating the fishery resources available. A further way in which the GIS should prove most valuable is in mapping conflicts between fisheries and in estimating the effects of these resource conflicts. Thus GIS can allow for an estimation of resource depletion or of resource availability along the zones of conflict, and having an objective graphical representation of the results of the conflicts could prove invaluable in resolving disputes via mediation or arbitration. It would be anticipated that such maps could prove also help in instituting a managment regime whereby fishing boundaries were seen as non-static, i.e. being variable on a regularly negotiated basis.

STUDY 9.20

TITLE: "Propositions d'usages de SIG en halieutiques"

AUTHOR: Le Corre, G.

PUBLICATION AND DATE: *Etude et Séminaire sur les Systèmes d'Information Géographique (SIG) en Méditerranée*. Vol.2. Commission des Communautés Européennes - Projet TR/MED/92/013.

Introduction/Objectives

The French marine research institute, IFREMER, have a number of developments in progress which are aimed at using GIS as a research and/or management tool. One such project is based upon marine fishing in the Mediterranean Sea. This project's objective is to create a set of analytical tools and some "scientific spatio-temporal simulations" which will allow IFREMER to model the interactions between fishery activities and other uses of coastal and maritime space. As one approach to the development of a marine fisheries GIS, it was decided to first create a prototype fisheries GIS, i.e. before even defining the precise functions of the future GIS. This would allow for some of the development considerations to become more obvious. The author notes that, in order to enable a fisheries GIS to function satisfactorily, it was necessary to rely upon the skills of people from a diverse range of interests, e.g. biologists, demographers, legal people, data processors, etc. He also noted that the prototype GIS could best be assembled within a framework of the following three functional classes:- (i) representation, (ii) analysis and (iii) simulation.

Methods/Equipment

The prototype fisheries GIS given is displayed simply in the form of a presentation to show the characteristics and capabilities of the software, i.e. it does not show any of the scientific results which would hopefully be achieved by a fully constituted system. All GIS work has been done on a UNIX workstation using ARC/INFO version 6.1.2. Data has come from IFREMER sources. The author illustrates his GIS by showing two distinct so-called "presentational GIS modules":

1. This first module is very much a simple representation of a so-called "library" of marine related data, with ideas being given as to how marine and fisheries related data could best be displayed.

2. The second module is a simulation which emphasises the potential for visualising complex fisheries situations and to interpret results from different input scenarios.

The database model upon which the graphics have been produced allows the map to be questioned according to several criteria:

(a) Spatial criteria, i.e. relative to distances, lengths, areas, etc. Selections of specific areas can be made by specifying sub-sets (windows) of the main area.

(b) Temporal criteria, i.e. changes over time can be evaluated using a so-called "ECHO" mechanism. This would allow the user, for instance, to select data for all the months of January and February between 1950 and 1980.

(c) Typological criteria, i.e. essentially questioning via a hierarchy of relevant themes.

Results/Discussions/Conclusions

Figure 9.32 is an example of output from the first presentational module. Here focus is made upon a small part of the Gulf of Lyons near Sete. Shown are bathymetric depth lines, isolines of distance from the coast, plus all the trawl haul tracks made over a particular time period. The screen image gives some indication of the various windowing possibilities and that a large range of display and data manipulation and analysis tools exist. Within most menu items there are sub-menus to allow for deeper questioning or analysis. Obviously the display could be variably zoomed, buffers could altered as required, time periods could be adjusted, etc. Once a desired screen image was obtained, the GIS functionality would allow for interrogation of the "visualized database". So for instance, based on the information shown in Figure 9.32, it would be possible to ask - "How many trawl hauls were made in water of x depth between time y and time z ? A host of other questions could also be posed.

Figure 9.33 provides an example of output from the second "simulation" module. Here it can be seen the some of the "library" of data held on the Gulf of Lyons area has been portrayed in a slightly different map form, showing factors such as the coastline, bathymetry, buffer zones, etc. The green areas on the Figure represent all marine locations which can be reached within certain time limits, and where the water is less than a specified depth. This simulation could also be considerably extended, with the general idea that it would be an aid to fishery deployment in terms of activity distribution from certain ports.

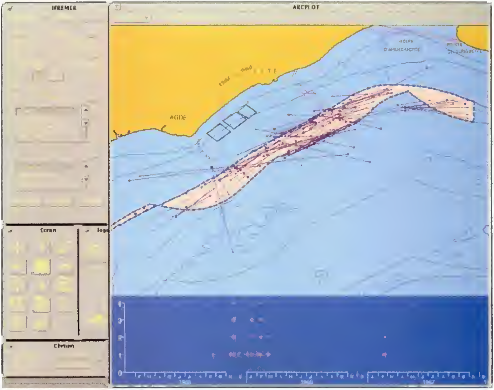


Figure 9.32 Screen From an IFREMER Developmental GIS Showing Trawl Haul Locations in the Gulf of Lyons, France

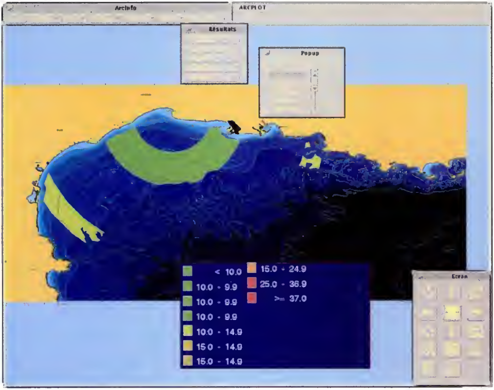


Figure 9.33 Screen From an IFREMER Developmental GIS Showing Simulated Fishing Activity Zones in the Gulf of Lyons, France

CHAPTER 10 - FUTURE TRENDS AND DEVELOPMENTS

10.1 Introduction

The importance of concluding with a short chapter concerning future trends and developments is in response to the rate of change which is apparent in the subject matters which we have discussed. If a subject constitutes an area which is comparatively static in terms of its progress or development, then presumably its contents can be reviewed without the need to make many conjectures or prognoses, except perhaps in terms of summarising what has been discussed. The subject matter of this Technical Paper certainly does not come under this category. The rate of change in the area of fisheries management is rapid, if not in practice then certainly in necessity. But the rate of change in the whole area of computer applications to management is probably far more rapid, and certainly progress in GIS is no exception. Figure 10.1 outlines these rapid developments by showing the life cycles of various facets of GIS, and from these cycles an estimation is given of the likely changes over the next five years (shaded area). Given this rapidity of change in both the fisheries and GIS scenes, then we can foresee a myriad of initiatives and developments, which need to be highlighted. This can probably best be accomplished by looking first at some likely developments in fisheries management which have a spatial component, and then by looking at future trends in GIS together with both negative and positive factors which are likely to effect its progress.

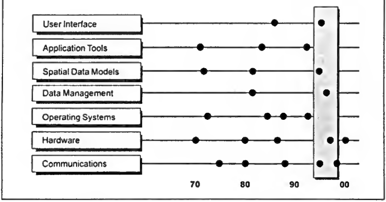


Figure 10.1 Innovative Life Cycles in Various Facets of GIS (after Maguire and Dangermond, 1994)

10.2 Future Developments in Fisheries Management Having a Spatial Perspective

One valid means of assessing the future direction in which fisheries management needs might take is to look at the proposed fisheries research agenda. Thus, if there has been a perceived need for a specific area of research then this must be as a consequence of the recognition that an aspect of management was in need of improvement. Figure 10.2 shows a summary of future research needs as proposed by the World Bank, in conjunction with the EC and the UNDP and FAO of the UN (World Bank, 1992). A casual perusal reveals the strong spatial element which pervades many of these headings. We intend here to briefly comment on some of the areas mentioned where GIS could play a leading part, and discuss some further important innovations. Even though they have a strong spatial connotation, we will not discuss factors which are of a more obvious and general nature such as "maintaining environmental quality" or "conservation of ecosystems and genetic diversity".

Box 4.1 Summary of applied research requirements

RESOURCE CONSERVATION AND MANAGEMENT
- Maintaining environmental quality
- Impact of man's activities on the environment and on fish production
- Assessment and monitoring of resources
- Modeling of ecosystems supporting exploitable resources
- Effect of pollution on aquatic resources
- Human health risks posed by consumption of fish from altered environments

FISH PRODUCTIVITY
- Fry and fingerling production
- Enhanced recruitment and habitat management
- Economic analysis of application of improved technology
- Conservation of ecosystems and genetic diversity
- Impact of nonindigenous species and stock enhancement
- Choice of species and farming systems
- Epidemiology and pathology of major diseases

COMMODITY CONVERSION AND UTILIZATION
- Selection of relevant technology for small-scale fisheries
- Improved vessel design and selective gear development
- Reduction of postharvest losses
- Utilization of small pelagic species
- Development of low-cost products
- Biotechnology and fish utilization

HUMAN LINKAGES, SOCIOECONOMICS, AND POLICY
- Assessment and monitoring of the economic and social state of fisheries
- Regulation of access, use rights, and resource rents
- Technical aspects of enforcement
- Social mechanisms in management of small-scale fisheries
- Social organization, gender, and equity issues in small-scale fishery communities

Figure 10.2 Summary of the Applied Fishery Research Needs as Seen by The World Bank

(a) The Growth of Mariculture.

We have already noted that fish production from "wild" stocks has probably reached a plateau, and that most of the future expansion of fisheries output is likely to come from the mariculture sector, plus the freshwater aquaculture sector. Although this sector grew rapidly during the 1980's and early 1990's, its rate of growth may have been somewhat retarded by the granting of the 200 mile offshore economic zone in the early 1980's. This allowed many coastal states, for at least a limited period, to have a greater security of fish supplies. This situation will undoubtedly decline and coastal states will turn to mariculture production at a faster rate. With

this will come the need for site selection. Three major developments in mariculture which will influence the spatial disposition of production are the production of a wider range of species, with their differing environmental requirements, the move towards production in deep ocean cages and production in fully enclosed, recycling water systems. These latter two developments will open up far more areas for production, and they will greatly shift the balance of site selection criteria. An excellent overview of the need for mariculture growth, and its implications for the future in the Canadian context, is provided by Cook and Black (1993). A significant part of their detailed paper is devoted to environmental planning for mariculture, and this is mostly in the light of the public's sceptical attitude to an activity which is known to have a range of possible negative influences. The authors specifically advocate the use of GIS as a major management tool.

(b) The Growth of Sea Ranching or Stock Enhancement.
A large number of studies worldwide have showed the potential for stock enhancement for a variety of species (e.g. Kitada et al, 1992). From the GIS viewpoint, what is important is that for this propagation method to be successful, then it essential that young stock are released into the wild in locations which can best provide for any individual production criteria. In many cases these criteria are still being established. When this has happened, then GIS is likely to prove the ideal medium for not only determining suitable locations, but also for monitoring both the relative success of alternative locations and the actual productivity of release locations.

(c) The Introduction of Fishery Property Rights.
With the whole concept of "fish hunting" being increasingly seen as an unsustainable process, then new methods of resource allocation are being investigated and implemented. Indeed some governments, e.g. New Zealand, now view the whole of their marine fisheries operations as being essentially "marine farming", with the state having ownership of the resource (retaining control of the "farm"), and the annual surplus production being harvested under an Individual Transferable Quota (ITQ) scheme. This sort of practice will rapidly become the norm, though agreements will be needed on the scale of controls (i.e. should they be at local, regional, state, national or at international level). There will also be regional variations in the selected methods of delivering these usage rights. These spatial considerations give a clue to the way in which GIS's will necessarily function as a means of "managing the farm", i.e. mostly in spatial allocation procedures and in monitoring current zone enforcements, as well as in helping to determine the need for any change in management zones.

(d) Controls Over Uses of the Coastal Environment.
This is a factor which is recognised as being particularly important to the future prospects for the development of small scale fisheries (World Bank, 1991). It is important that a thorough understanding of ecosystems and their interactions are gained, and GIS can play a major role in this. But of far more importance is the ability of GIS to allow for computer based modelling of the complex interactions which inevitable occur in this area (zone) of resource use conflict. It is particularly important that all levels of participation are involved in decision making with regard to coastal zone use. Decisions about coastal areas cannot be made without spatial information.

(e) The Creation of Marine Reserves.
It has long been recognised that marine areas, such as coral reefs, offer huge protection to a variety of species, i.e. since reefs considerably reduce the ability of humans to carry out harvesting. The development of alternative marine reserves may take two forms:

(i) The simple placing of fishery restrictions in specified areas or,

(ii) the creation of artificial "reefs" which offer fish purposefully build refuges, as a means of increasing their numbers.

The identification of such sites will prove to be a major task for GIS functionality. Inputs to any such GIS would need to cover the whole area of species environmental preferences, plus factors such as the variable sociological needs for such reserves, reserve boundaries, the integration of tourism, rehabilitation of adjacent ecosystems, etc.

(f) Long Term Global Climatic Changes.
A large amount of research has been in progress which is concerned with so-called "global warming", i.e. the build up of greenhouse gasses in the atmosphere which are leading to higher average temperatures. Several authors have detailed the likely effects that this will have on fisheries (see especially Bigford, 1991 or Glantz, 1992). We cannot mention all the consequences here, but it must be clear that rising sea levels will have a huge impact on a variety of coastal ecosystems, causing changes in their distribution and composition. Displacement and alterations of habitats will thus ensue. There will be changes in world average sea water temperatures which again will directly cause biological species displacements, and indirect displacement will occur through changes in ocean current circulations and the location of upwellings (Hsieh and Boer, 1992). GIS is already being used as a major tool in climatic modelling and prediction, and it will obviously have a major role to play in determining the likely impact that global warming will have on all facets of fisheries management.

(g) The Concept of Variable Spatial Management Entities.
In the past not much thought was given as to what best constituted a unit of fisheries management. Over the past few years there have been interesting developments in this field. One management unit which is now recognised is the Large Marine Ecosystem (LME), i.e. a geographical entity consisting of unique bathymetry, circulation, biological productivity and trophodynamic interrelationships, into which a species has become adapted. More recently the concept of a Marine Catchment Basin (MCB) has been described. This is an entity which recognises the linkage between a marine area and the river catchments which service that area. At another level there has emerged the recognition of community based fisheries management, with its emphasis on a bottom-up approach, and with the idea that local people can best organise and manage their fish resources. Clearly, these variable units of management may bear no relationship to established political boundaries. It may therefore be necessary to establish "co-management" systems to best organise fisheries exploitation in any single area. Under the potentially complex access rules which will evolve, then a spatial management system such as that provided by GIS may be crucial.

(h) The Imposition of Controls Over High Seas Stocks.
Following the success of the instigation of the UNCLOS 200 mile coastal EEZ in the early 1980's, the United Nations has recently debated the imposition of fisheries controls on the open oceanic waters, i.e. with a view to managing straddling and highly migratory fish stocks. An agreement has been reached on this (August, 1995), which imposes a system of licenses, quotas, inspection measures and penalties as a means of enhancing conservation. Given that this agreement must cover more than 50% of the surface of the Earth, then spatially based management procedures are inevitable. Here again the role of GIS would firstly be in the straight-forward mapping out of zones, quotas, allocation rights, etc, and then in the recording of activities for each area. Based on the data shown, regular revues would then be made before further management decisions were taken. These decisions would not be made without the obvious inclusion of prescriptive spatial modelling to evaluate alternative production or allocation scenarios.

(i) The Implementation of On-Board GIS.
We have previously indicated that most modern trawlers are now equipped with an array of electronic navigation, chart plotting and acoustic SONAR instrumentation. In the immediate future we will see the ability of vessels to either carry their own databases and GIS functionality, or this information will be distributed to them on demand. Already we have shown how satellite meteorological and water temperature data is being transmitted. The vessel will then have the capability to match this data to other water parameter or bottom type data, in order to provide additional information. This may be especially important under severe conservation management regimes, perhaps in areas of specific bio-diversity, habitat or ecosystems needs.

(j) The Development of Integrated Fisheries Management Models.
Several authors, notably McGlade and McGarvey (1992), have stressed the need for the implementation of what they have termed "Integrated Fisheries Management" (IFM). This means that instead of just relying on biological and ecological factors (or modelling) as a basis for making management decisions, socio-economic considerations are also introduced. So factors concerning the market, prices, alternative sources of income and the variable behaviour of fishermen are also considered by fisheries managers when deciding on management strategies. If IFM becomes the norm, then clearly fisheries management becomes a much more complex procedure. Since spatially variable criteria are being introduced, i.e. the various socio-economic factors, then again GIS can serve as a further tool to expedite the necessary modelling.

(k) The Reduction of By-Catch Losses.
Although many recent developments in fishing gear design has gone into purposefully reducing by-catch (non-target species) losses, this is still a problem which is far too common in some fisheries. The problem must be seen in terms of not only protein and catch effort waste, but also of ecosystems damage, and the negative effects which are being felt on species whose populations are already threatened, e.g. turtles, dolphins and porpoises caught in seine nets and albatrosses on longlines. For the problem of by-catch losses to occur in the first place, certain spatially variable conditions must exist. GIS is needed as tool to both discover what the parameters of these conditions are, and to help develop strategies of avoidance.

10.3 Factors Influencing GIS Progress

Clearly there are a huge range of factors which will influence the progress which GIS makes over the next few years, and these factors may vary quite markedly from region to region. It seems important that we give some indication of what these factors might be, if only so that the prospective GIS purchaser has an indication of matters to be cogniscent of. A major source for these factors influencing progress was CCTA (1993). The factors can be divided into positive factors and negative factors, and they are listed briefly in Table 10.1.

Table 10.1 Major Influencing Factors on the Progress of GIS

POSITIVE INFLUENCES

* Continuing hardware cost reductions and improved performance.
* Improvements in storage capacities and performance.
* The improved capability and functional range of most software.
* The adoption of standards for GIS in many countries.
* The availability of a greater range of digital data sets.
* The movement towards object-oriented databases.
* A greater range of back-up, guidance and support services.
* The greater recognition of GIS as valuable management tool.
* The perceived success of GIS in a number of varied fields.

NEGATIVE INFLUENCES

* The lack of government funding for basic research initiatives.
* The lack of funding to purchase GIS's per se.
* Too many systems are stand-alone applications having little incentive to progress.
* The necessary implementation procedures are very complex.
* Data costs can be prohibitive.
* Too frequently data is difficult to integrate for reasons of structure, accuracy, scale, level of aggregation, etc.
* The difficulties of achieving definitive cost/benefit analyses deters managers from making purchase decisions.
* Pilot studies often do not live up to expectations.
* Suitably qualified staff are still difficult to obtain.
* Legal concerns over the copyright of data.
* Data gathering systems can be very difficult to instigate and maintain.
* User interfaces are still very complex.

Although this Table indicates a substantial number of negative influences on the current and immediate future prospects for GIS, we do not believe that the sustained growth in GIS proliferation will be halted. We say this because there is a huge deployment of research and development effort going into GIS from private, and to a lesser extent, public funding. Most of

the negative influences will thus be reduced, although there will always be challenges to be met. Also, the price advantages that are occurring, and are likely to continue, are really quite dramatic. This will greatly increase the GIS market. Other future developments, most of which will have a positive impact, are discussed in the following final section.

10.4 Trends in Geographical Information Systems Development

In this section we have put together a number of the major trends, developments and key issues which we see as being of current importance to the future direction and progress of GIS. Where possible we have avoided trends which are occurring in the more general field of computing or information technology, i.e. even though these will have a profound impact on GIS capability. We recognise that many of these trends may not be directly beneficial to a marine fisheries GIS, but they are all developments which any GIS user should be aware of. They are not placed in any particular order.

(a) Changes in Mapping Detail Capture Methods.
It seems increasingly likely that there will be a slow decline in the need to digitise. This will come about as the availability of pre-digitised data increases and as scanning quality improves.

(b) Data Structures, Algorithms and Storage.
These are three areas of pure GIS, to which a great deal of research interest is being given since there are pressing needs to make progress here. Thus present ways of structuring data are too varied and non-susceptible to conversion between various data models. Efficient methods of storage for the vast data sets of the future still has to be researched, though rapid advances are being made.

(c) Visualization and Graphical Display.
In the near future this area of GIS is likely to witness major advances, i.e. as the design of output displays is of critical importance to how people perceive spatial arrangements, and how they interpret them. Interest is now being shown in the design of animated displays, three dimensional display, continuous colour gradations, etc.

(d) Processes of GIS Adoption.
Goodchild (1992) sees research into improving the institutional environment for GIS as being of paramount importance. This includes an understanding of the processes of GIS adoption, the effects of GIS on an organisation, the real benefits of GIS and the processes for actually utilising GIS in decision making.

(e) Towards a 4-D GIS.
Demands from commercial activities which are wealth creating in the sense that they are exploiting subterranean natural resources, are sufficient to ensure that a great deal of 3-D and 4-D GIS research is in progress. The first basic 3-D GIS's are now available, but they have yet

to be applied in the marine context. This is an area where there will be huge advances during the next decade. The main areas for this research are outlined briefly in Gurney and Mason (1992).

(f) The Incorporation of Error Handling Procedures.
It is of paramount importance that future GIS software should be able to detect likely errors in datasets as a way of improving the validity of output.

(g) The Adoption of Intelligent GIS.
With the emergence of massive databases and data sets in the near future, it could well be beyond human capability to discern spatial patterns in mapped data. Thus Oppenshaw (1993) states, in relation to GIS analyses, that it is beyond reason to assume that we should know in advance what we are looking for, or where to find it, or when to find it. GIS will need to incorporate fully automated intelligent pattern and relationship "hunters" that can cope with the complexities of GIS output.

(h) The Ownership of Data.
The reader will be generally aware of issues relating to copyright. This matter is subject to problems in the GIS sphere since, although it may be clear who owns particular data, it is not so clear as to how ownership rights are affected if various levels of changes are made to purchased data.

(i) The Introduction of Meta Databases.
It is fairly clear that in the near future most GIS software will incorporate specific meta database organisational functions within the GIS package. This should greatly improve database management.

(j) Multi-Media GIS.
Allied to visualization is the concept of multi-media GIS. As well as incorporating static images, multi-media GIS will soon be developed which allow for the integration of moving video images, sounds and eventually virtual reality into the GIS display. Although this is already technically possible, at the present time it is still rather "gimmicky", and it remains to be seen whether a valid place will be found for multi-media GIS in the field of fisheries management.

(k) The Adoption of Standards in GIS.
If GIS data inputs are to be efficiently shared around and between large user communities, then improvements in standards are vital. Standards are needed not only in terms of the data formats and structuring used by a particular organisation, but also across all organisations and between various countries. In order to obtain standardization it will be necessary for software companies to reveal their present file formats, and then to enter into discussions so as to agree on universal "open" formats. Additionally, standards will need to be agreed on factors such as data quality, processing methods, data collection methods, etc.

(l) The Proliferation of Data Collection Devices.
We saw in Chapter 2 that there was a variety of electronic data collection equipment. As yet many of these instruments are only slowly being adopted. As their adoption rate increases, then so too will the availability of readily usable digital data emanating from them. This will provide greater opportunities for the use of GIS.

(m) The Availability of Data.
In section 2.3.4 we discussed the availability of secondary digital data. It should be apparent from this that the data volumes available, from sources such as RS and digital mapping agencies, are proliferating at an exponential rate, and this availability is being matched in relative data price reductions. It would appear that there will also be greater freedom of access to data in many countries, i.e. if only in response to the fact that data sales can be a much needed source of government revenue. And data will be more readily available via various data transfer networks. All these trends will greatly enhance the scope for GIS working.

(n) The Development of More Specialized GIS's.
It could be argued that, with the move towards truly distributed GIS, then each single GIS will concentrate on more specialised functions. This could lead to more specialist or customised GIS software. With this trend there might also be a move towards the integration of various additional software programs, i.e. as these specialist GIS's accrue added tasks after implementation.

(o) Changes in the GIS Software Houses.
At the present time there are dozens of different software suppliers. As GIS becomes more standardised at a universal scale, then there will undoubtedly be less need for such a range of systems or suppliers. This will lead to both closures and company buy-outs or mergers. It is also likely that the profit margins on systems will decline so the companies supplying GIS packages will also take on the distributing of data sets (where the market is much bigger) as a means of raising income.

(p) New Operating Systems.
The emergence of the Microsoft Windows New Technology (NT) family of operating systems will allow for computer systems at the lower end of the computing spectrum to access data which is managed by "high end" systems. This will have the effect of allowing GIS at all levels to integrate into all sorts of other software and GIS systems. In effect, the distinction between PC and Workstation GIS will disappear because the PC user will have complete access to all the workstation functioning.

(q) The Development of Object-Oriented Systems.
In Section 6.5.1 we introduced object oriented databases. The introduction of object orientation into GIS will affect more than just database management. It will also support the development of user interfaces which are easier to use, allow for the realization of data models which are more user oriented, allow for easier software programming, and allow for better database update transactions.

What has been briefly described above are only some of the many ways in which GIS is developing. Because of this variety of change, and because the actual rate of change is so rapid, then we must conclude by stressing to the reader the fundamental importance of keeping abreast of developments. This can best be achieved, where possible, by attending GIS courses and conferences, by subscribing to trade journals and magazines, by updating GIS software when applicable, by joining professional associations and by being interested and involved in GIS in the workplace. And some time must be also found for keeping up to date with progress in the marine fisheries world!

GLOSSARY OF TERMS AND ACRONYMS

The terms and acronyms listed in this glossary have been deliberately selected with a bias towards terms associated with GIS, i.e. rather than to any terms which might be used in the fisheries management field. In some instances acronyms have not been listed here - this is when they simply appear once as part of a table or list, e.g. as a list of GIS supporting organizations, or when they form the name of a software product or a particular purpose built software system, or where they form the name of a company.

2.5-D	A dimensional system in which height or depth is tied to the surface plane.
Active sensor	A sensing device which illuminates an object with its own radiation source and then captures the echo received.
AES	Atmospheric Environment Service.
AGI	Association of Geographic Information. A UK based umbrella association coordinating the GIS industry and activities in Britain.
Algorithm	A procedure for performing a specific action; or a set of instructions to the computer which provide a guaranteed solution to a specific task.
Alphanumeric	Consisting of both letters and numbers.
Annotation	The alphanumeric text or label appended to a map.
Area	A bounded, continuous two dimensional surface which may include its boundary. Usually defined in terms of an external polygon or a set of grid cells.
ASCII	American Standard Code for Information Interchange; an 8 bit coding system used to represent alphanumeric characters in computers.
Attribute	Any non-spatial characteristic of an object.
Autonomous GPS	The receipt of information from a single global positioning satellite about the location of the receiving device. In this case the result would not be very accurate, i.e. typically only to the nearest 100 metres.

AVHRR	Advanced Very High Resolution Radiometer.
BDRM	Regional Maritime Database; of West African countries.
Benchmark	A series of exercises which may be given to a software company by a prospective GIS purchaser, in order to see how well the particular software can perform a range of tasks.
Binary	A number system which uses the base 2 and has only the digits 0 and 1.
Bit	In digital computing, a binary digit; the smallest element of information.
BMFD	British Marine Fishes Database.
BODC	British Oceanographic Data Centre.
Boolean logic	The use of certain operators in a command given to a computer, e.g. such as "AND" or "NOT", so as to show the sort of conditions which need to be met before the command is carried out.
BPI	Bits Per Inch; a measurement of linear data density on magnetic storage materials such as tape.
Buffer	A uniform unit of area around an object.
Byte	Unit of digital data, usually that required to store a single character, typically eight bits.
CAD	Computer Aided Design.
Cadastral	Concerned with property ownership, particularly for taxation purposes.
Cartography	The science and practice of representing the features of the Earth's surface graphically (in map form).
CASI	Compact Airborne Spectrographic Imager; a sensor used to determine the spectral signatures of objects on the Earth's surface.
CCT	Computer Compatible Tape; magnetic tape containing data in computer readable digital format.

CD-ROM	Compact Disk - Read Only Memory.
CDT	Conductivity/Salinity, depth and temperature recorder.
CECAF	Fishery Committee for the Eastern Central Atlantic.
CGIS	Canadian Geographic Information System; one of the earliest GIS installations.
Choropleth	Mapping type which is based on unit areas of equal value.
Connectivity	A relative measurement of how well a settlement is connected to other settlements by, for instance, any transport network.
Contiguity	The relative degree of adjacency between neighbouring areas.
Coordinate	A set of numeric quantities that designate position in a given reference system.
COWLIS	Coastal Ocean Water Level Information System.
CPU	Central Processing Unit; that part of the computer which is responsible for numerical calculations and control.
CPUE	Catch Per Unit of Effort.
CRT	Cathode Ray Tube.
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia).
CZCS	Coastal Zone Colour Scanner.
DAT	Digital Audio Tapes.
Data	A general term which may describe numbers, characters or groups of bits suitable for processing by a computer.
Database	A collection of related observations or measurements held within the computer.
Data capture	The creation of digital data from existing information sources.

Data logger	An automatic or semi-automatic device used to collect and record data.
Data model	The rationale for a particular data organisation scheme within a database.
Data structure	Organisation adopted for the data held in a digital database.
DBMS	Database Management System; software to control the storage and retrieval of integrated data holdings.
DEM	Digital Elevation Model (see DTM).
DFO	Department of Fisheries and Oceans.
DFONET	Department of Fisheries and Oceans Ocean Information System.
Differential	The use of two or more global positioning GPS satellites as a means of determining an exact location on the Earth's surface, i.e. by giving a latitude and longitude coordinate reference with an accuracy of about one metre.
Digital map	A map which can be displayed on a computer screen using previously digitised data.
Digital number	The numerical value of a specific pixel.
Digitiser	A device which converts analog information into a digital format. The device is commonly used to transform graphical (mapped) information into digital format.
DIP	Document Image Processing.
Directory	A collection of information about whole datasets.
Disk drive	The basic storage device of a computer system.
Distributed	Where computers, and especially databases, are computing linked in a wide area network so as to take advantage of distant databases.
dpi	Dots per inch.

DTM(i)	Digital Terrain Model; a digital representation of relief. Usually a set of elevation values incorrespondence with a grid cell. (ii) Desk Top Mapping; the inception of simple GIS techniques into normal business computing practices.
E-Mail	Electronic Mail; the communications system whereby messages can be sent from one computer to another with the use of networking.
ECDIS	Electronic Chart Display and Information System.
Edge matching	The process of ensuring that data along the adjacent edges of map sheets matches, i.e. in terms of both position and attributes.
EEZ	Exclusive Economic Zone.
EMR	Electromagnetic radiation.
EOSAT	Earth Observation Satellite.
EPA	Environmental Protection Agency.
ERS-1	The first Earth Resources Satellite, launched by the European Space Agency.
ESA	European Space Agency.
ESIS	European Seabed Information Service.
ESRI	Environmental Systems Research Institute; the software house which produces Arc/Info GIS.
False colours	The assigning of arbitrary colours to data values in a remotely sensed image.
Feature code	An alphanumeric code which describes and/or classifies geographic features.
FFIS	Foreign Fishery Information System.
Field	A subdivision of a record which contains one unit of information, e.g. the answer to a single question.
File	A collection of related information stored in a computer; often part of a database.

Format	The physical organisation of data elements within a dataset.
FOV	Field of View: the angle through which a sensing instrument is sensitive to radiation.
GEBCO	General Bathymetric Chart of the Oceans.
Generalisation	The smoothing of lines on a map so that the outline becomes less complex, or the simplification of the image of a map as for instance occurs when scale changes are made from large to small.
GENIE	Global Environmental Network for Information Exchange.
Geocoding	Allocating a code to represent the spatial characteristics of an entity.
Geodesy	The branch of mathematics which is concerned with making accurate measurements of large portions of the Earth's surface.
Geomatics	The complete geographical information technologies.
Geo-reference	The grid coordinate allocated to a particular location as a means of linking an object with that location.
Geostationary	A satellite which orbits above the equator at Satelliteapproximately 36 000 kms, such that its period of revolution about the Earth matches the Earth's rotational speed.
Geostatistics	A branch of statistics which is concerned with the mathematics of spatial surfaces.
GFCM	General Fisheries Council for the Mediterranean.
Gigabyte	1000 megabytes.
GIS	Geographic(al) Information Systems; the hardware and software systems necessary for capturing, storing, editing, integrating, manipulating, analysing and displaying spatially referenced data.
GISCO	Geographic Information Systems of the European Community.
GIST	Geographical Information Systems Tutorial; a GIS training software package.
GISTARS	Geographic Information STARter System; a GIS training package.

GPS	Global Positioning System; a set of satellites which transmit signals which can be decoded by receivers to determine positions anywhere in the world.
Graphical data	Data which can be used to create a graphical representation of objects in the real world, i.e. data referring to the outlines on a map.
GRID	Global Resources Information Database (of the United Nations Environment Programme).
Ground truth	The information gathered about the Earth's surface at the same time as a satellite pass is made, i.e. in order to interpret and calibrate remotely sensed observations.
GUI	Graphical User Interface: a computer user interface which makes use of graphical objects, such as icons, for the selection of options, and usually has a windowing capability enabling multiple windows to be displayed on the screen.
Hardware	The physical equipment in a computer system.
HMMR	High-resolution Multifrequency Microwave Radiometer.
HO	Hydrographic Office (in the UK).
ICCAT	International Commission for the Conservation of Atlantic Tunas.
ICES	International Council for the Exploration of the Seas.
ICLARM	International Center for Living Aquatic Resources Management.
ICOIN	Inland Waters, Coastal and Ocean Information Network.
IDIAS	Ice Data Integration and Analysis System.
IFM	Integrated Fisheries Management.
IFOV	Instantaneous Field of View; a term used to describe the ground resolution of a remote sensing scanner.
Image analysis	The transforming and interpretation of remotely sensed digital data, with the help of special hard- and software systems.

Inmarsat	A new series of communication satellites which will be used by global positioning systems to give highly accurate locations on the Earth's surface.
Interactive	The operation of a computer system through processing continual, instantaneous communication between the operator and the machine.
Internet	An international computer communication system over which information is distributed.
IOC	Intergovernmental Oceanographic Commission (of the United Nations Educational, Scientific and Cultural Organization)
Isolines	Lines on a map which join places having equal values, e.g. contour lines.
Isotropic	Pertaining to surfaces on the Earth which are uniform in all directions.
IT	Information Technology.
ITQ	Individual Transferable Quota.
JANET	Joint Academic Network; a UK computer network linking academic and research sites.
Kilobyte	One kb = 1024 bytes.
Kriging	A spatial interpolation technique which was originally developed in the mining industry.
LAN	Local Area Network; the linking of computing systems, usually within a single department.
Landsat	A series of US polar orbiting satellites, first launched in 1972 by NASA, which carry both the multispectral scanner and thematic mapper sensors.
Layer	A subset of digital map data which contains information all relating to one subject, e.g. water quality or the coastline.
Line	In GIS it is sometimes called an arc, a link or a segment. It is a line segment which directly links two points (nodes) on a map.

LIS	Land Information Systems; a GIS for land resources management and an acronym given to some early GIS's.
Liveware	The name sometimes given to the personnel who operate computer systems.
LME	Large Marine Ecosystem; areas of the sea having unified hydrographic regimes and trophically related marine populations.
MARIS	Marine Information Service.
MARSIS	Marine Remote Sensing Information System.
MCB	Marine Catchment Basin.
MEDS	Marine Environmental Data Service.
Megabyte	One Mb = 1,048,576 bytes.
Meta database	A database which gives details about all the datasets which make up any database, e.g. date when data was gathered, source of data, format of data, etc.
Microcomputer	A small stand-alone computer processing unit.
MODEM	A MOdulator-DEModulator: a digital device which allows computers to communicate with each other via the telephone network.
Mosaic	A map or satellite image, compiled from several different images.
MSS	MultiSpectral Scanner; a remote sensing device that records electromagnetic energy in several wavelength bands simultaneously.
Multimedia	The use of text, data, still and motion video, sound and computer graphics by a software programme to form a composite display.
NAFO	North Atlantic Fisheries Organisation.
NCGIA	National Center for Geographic Information and Analysis: a US research center for GIS.
NCIC	National Cartographic Information Center.

Network	(i) The physical configuration of cables, hard- and software allowing for communication between computers at different locations. (ii) The data structure for route diagrams, shortest path analysis, etc.
Networking	The use of a computer plus a MODEM link to obtain access to remotely held databases.
Nimbus	A series of US Earth observing experimental weather satellites which carried a variety of sensors, the last of which was launched in 1978. They are now non-operational.
NLR	National Aerospace Laboratory; a Dutch distributor of remote sensing products.
NOAA	National Oceanographic and Atmospheric Administration.
NODC	National Oceanic Data Center.
Node	The start or end of a link or line; a point which can be shared by several lines.
NOS	National Ocean Service.
NRSC	National Remote Sensing Centre.
NTF	National Transfer Format. The UK standard for the transfer of geographic digital data - it has now become a British Standard (BS7567).
NWI	National Wetland Inventory.
Object	Computer programmes which use object oriented oriented techniques and languages. These employ a programming data centred approach to programming, based on the definition of "objects".
OCM	Ocean Color Monitor.
Octree	A representation for compressing data which is geo-referenced in 3-D (using voxels).
ODES	Ocean Data Evaluation System.

Operating	The high-level administration programme running system in a computer at all times, i.e. to control all the operations and tasks, e.g. MS-DOS and UNIX.
Optical disk	A data storage device having a disk whose coating can be altered to encode information. Data is read from the disk by means of a laser.
Orthophoto	A photograph which has been manipulated so as to eliminate image displacement due to photographic tilt and relief.
OS	Ordnance Survey (Great Britain).
Overlay	A set of graphical data which can be superimposed on to another set of graphical data. Sometimes used as a synonym for layer.
Package	A generalised programme capable of performing several operations and covering the requirements of many users.
Passive sensor	A device which captures and records natural radiation reflectance levels.
Peripheral	Any hardware device added to a computer system.
Photogrammetry	The technique of obtaining precise measurements from images.
Pixel	From Picture Element: the smallest unit whose characteristics may be uniquely determined; an individual dot on the screen.
Platform	In remote sensing, the physical object which carries the sensors that make the remote measurements.
Plotter	A device used to record information, such as maps or graphs, on paper or film. They are usually based on one or more pens which move over the medium under control of a computer.
Polar orbiting	The path of most orbiting satellites, i.e. those which circumnavigate the Earth about 15 times per day and which pass almost over the poles on each orbit.
Polygon	A closed, two dimensional figure with three or more sides and intersections, e.g. a geographic area such as a field or other land unit.

Preprocessing	The manipulation of data, via a large number of techniques, to make it suitable for further manipulations or analysis.
Primary data	Data which has been directly gathered from real world situations by surveys, questionnaires, measurements, etc.
Programmable	Any computing or data recording device which can be pre-programmed to carry out any desired functions.
Projection	The systematic construction of features (physical and political) on a plane surface to represent corresponding features on a spherical surface.
Protocol	In data communications, a set of rules which determine the formats and conventions by which information may be exchanged between different systems.
Push broom	An airborne sensor which functions by taking sensorcomplete frames (pictures) of any scene over which it passes.
Quadtree	A spatial data structure based on successive subdivision of an area, the purpose of which is to minimise data redundancy.
Radiometer	A passive device for intercepting and quantitatively measuring electromagnetic radiation in a band of wavelengths.
RAM	Random Access Memory; a type of chip based memory which a computer processor can read data from and write data to.
Raster	A format for storing, processing and displaying graphic data in which graphic images are stored as values for uniform grid cells or pixels.
RDBMS	Relational Database Management System: a widely used strategy for data organisation in GIS software.
Record	A collection of related fields, e.g. all the responses from one questionnaire.
Registration	The superimposition of locations on one image with the corresponding locations on a second image or map.

Remote sensing	Obtaining information about an object or phenomenon without any direct contact, e.g. via the use of satellite sensors or Radar.
Resolution	The minimum size of a feature which can be reliably distinguished by a remote sensing system.
RESTEC	Remote Sensing Technology Center.
ROM	Read Only Memory; a type of chip based memory which a computer processor can read data from but cannot write data to.
Rubber	A GIS process that geometrically adjusts map sheeting features to enable a digital map to fit a designated base.
Run-length	A method of digital coding which saves on the encoding amount of data which needs to be stored.
SAR	Synthetic Aperture Radar; a radar system based on a series of elemental antenna units, or sequences of observations from a single antenna, from which the effective antenna is mathematically constructed through signal processing.
Scanner	A device used to capture data digitally from a paper map or other graphic representation.
Seasat	A polar orbiting, earth observation satellite designed to gather information about the oceans. Although the satellite only operated in 1978, much of its synthetic aperture radar data is still useful.
SeaWIFS	Sea-viewing Wide-Field-of-View Sensor.
Secondary data	Data which has been acquired from previously published sources.
Sensor	A device that gathers electromagnetic radiation or other physical data and presents it in a form suitable for obtaining information about the environment.
Signature	A set of spectral, tonal, temporal or spacial characteristics that together serve to identify a class or feature by remote sensing.
Software	A computer programme written in a high or low level language.
Spaghetti data	A simple vector data structure comprising feature codes and co-ordinates without any topology.

Spatial data — Data or information describing the geographical position or location of an object.

Spectral — Typical radiation reflectance values as given signatures off by different ground or water surfaces.

Spline — A mathematical formula for drawing regular function curves.

SPOT — Satellite pour l'Observation de la Terre. A French multispectral remote sensing satellite system having pointable sensors, which was first launched in 1986.

SQL — Structured Query Language; a query language interface for relational databases. It is used to define, access and manipulate data stored in these databases.

Standards — In computing, the establishment of a unified set of procedures for handling digital data.

Swath width — The area on either side of a platform which is surveyed by a remote sensing instrument.

SYMAP — Synagraphic Mapping System; one of the earliest and most widely used computer mapping systems, producing crude line printer output graphics.

TAC — Total Allowable Catch.

Telnet — Telecommunications Network.

Thematic map — A map depicting one or more specific themes, e.g. rainfall or population density.

TIN — Triangulated Irregular Network; a variable resolution data structure for surface models, based on a Delaunay triangulation. It is based on a series of non-overlapping triangles which completely cover any surface.

TM — Thematic Mapper; a seven channel multispectral scanner sensing device, designed for monitoring the Earth's surface, and flown on the Landsat series of satellites.

Topography — The collective features of the Earth's surface, including relief, hydrology and cultural features. The features may be accurately located on topographic maps.

Topology — A geographic data structure in which the inherent spatial connectivity and adjacency relationships of features are explicitly stored and maintained.

Transducer — That part of the acoustic sonar system which converts an electrical signal to a mechanical vibration in order to move adjacent water particles so as to cause a pressure wave.

Transformation — The ability to change from one coordinate system to another. Sometimes also called rectification.

Turnkey system — A complete computer system consisting of a hardware and software combination which has been assembled in order to perform a specified range of tasks.

UKDMAP — United Kingdom Digital Marine Atlas.

UNCLOS — United Nations Convention on the Laws of the Sea.

UNEP — United Nations Environmental Program.

Unique — An alphanumeric coding given to any object identifier which is listed in a table, which allows for its identification and allows it to be matched with other objects.

USGS — United States Geological Survey; the organization dealing with US governmental topographic mapping.

USNO — United States Naval Observatory.

UTM — Universal Transverse Mercator; the most frequently used (in GIS) map projection system. A series of north-south zones are established, and locations are designated in terms of distance in metres east of the western edge of the zone, and north or south of the equator.

VDU — Visual Display Unit; commonly thought of as a computer screen.

Vector	In GIS, the basis for representation of spatial information in which objects are defined as either points, lines or polygons, and these are processed in terms of x,y coordinates.
Videography	The use of video cameras on airborne platforms to capture images of the Earth.
Visualization	The processes whereby graphical information may be perceived, i.e. any one map be interpreted differently by any two people in accordance with their inherent perceptual capabilities.
Voxel	A data structure used to assign geo-references in a 3-D spatial model.
WADABA	Wadden Sea Data Base.
WAN	Wide Area Network; the link up of computing systems over a wide spatial area.
WATIS	Wadden Sea Information System.
WINS	Weather Information Network System.
WOCE	World Oceanic Circulation Experiment.
Workstation	A high performance personal computer aimed typically at scientific and technical users. It usually runs using the UNIX operating system. Most of the more powerful GIS's run on work stations.
WVS	World Vector Shoreline.

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This review documents the available literature on geographical information systems (GIS), including as much information as possible from both scientific papers and local reports. It examines the status of GIS methodology and technology and the application of GIS to marine fisheries. Analysis of crises in the world's marine fisheries reveals that common elements are different manifestations of spatial inequity. The most frequent form of inequity is in access rights to the resource. Variations in resource depletion, spatio-temporal variations in stock recruitment, imposition of regulatory zoning, destruction of marine ecosystems and siting of mariculture facilities are other examples. The need for improvement of spatial management practices is emphasized. The following questions are addressed: Does the use of GIS, in combination with other analytical tools and models, allow for more efficient decision-making? How would it be best to implement a marine fisheries GIS? How can sufficient guidance and support be obtained to ensure its continued success? The publication presents 19 case-studies related to applications of GIS techniques to marine fisheries.

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